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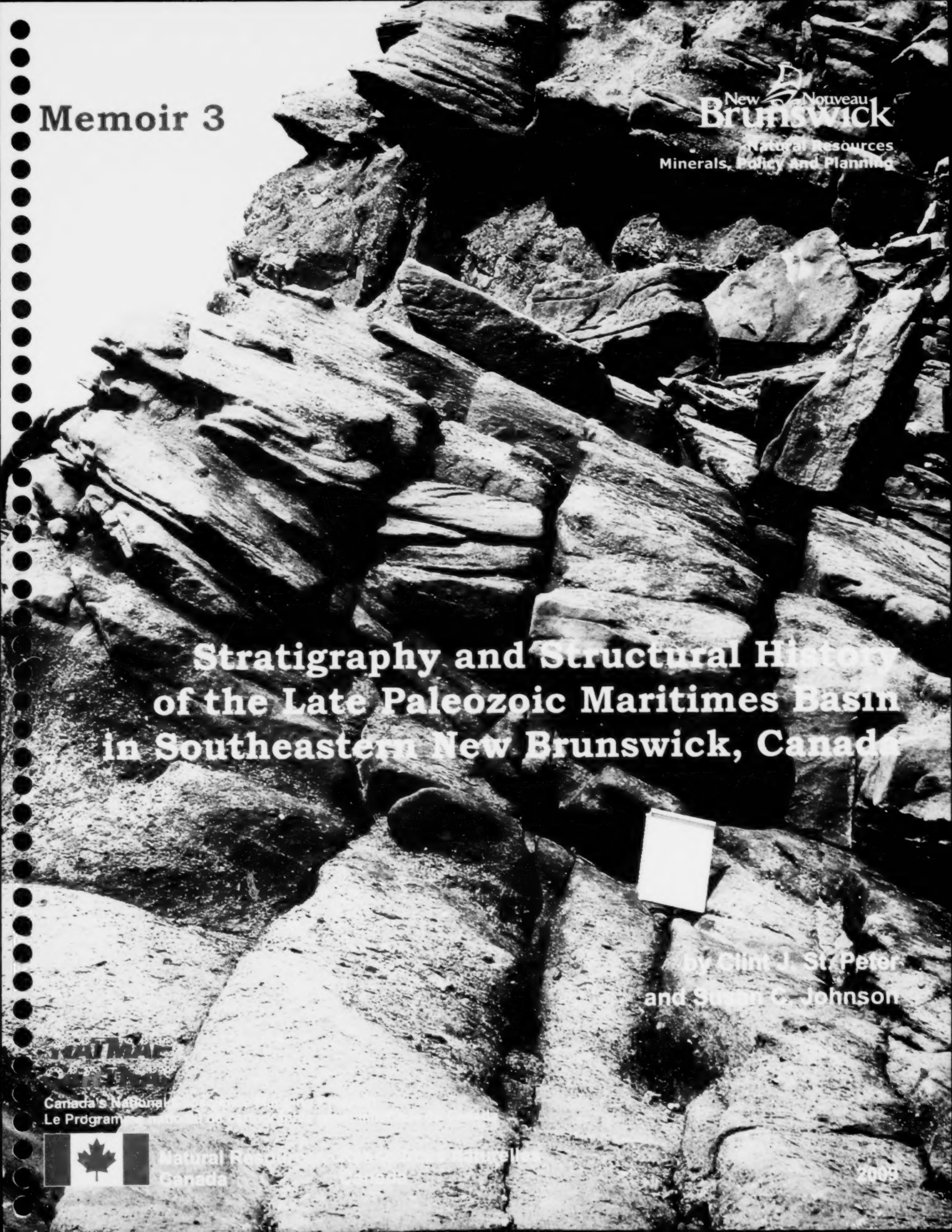

Stratigraphy and Structural History of the Late Paleozoic Maritimes Basin in Southeastern New Brunswick, Canada

by Clint J. St. Peter
and Susan C. Johnson

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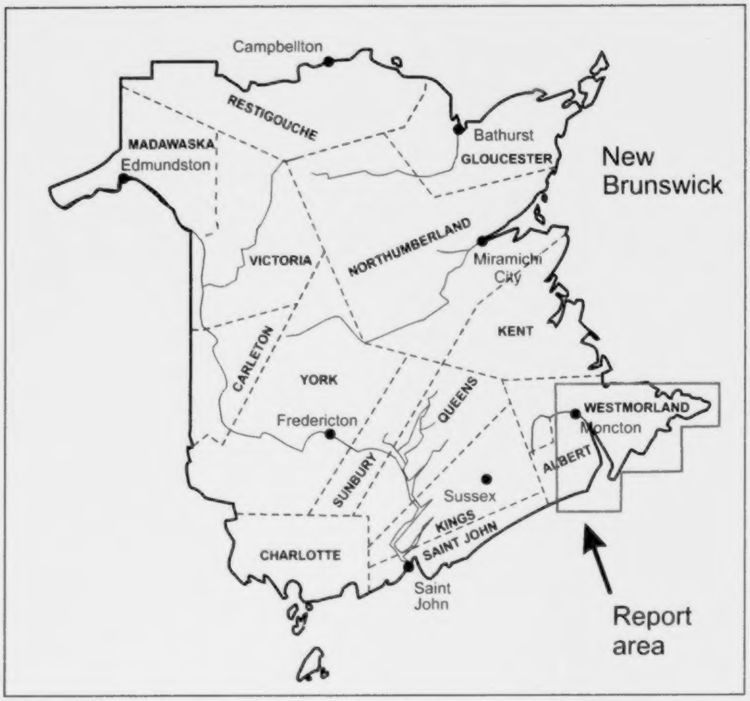
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Stratigraphy and Structural History of the Late Paleozoic Maritimes Basin in Southeastern New Brunswick, Canada

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Don Vail, photographer and imaging specialist, prepared and enhanced the cover photograph and all photographs in Chapter 2. Most images in the report were taken by NBDNR staff. Don J.J. Carroll (formerly with NBDNR) also kindly photographed some of the sites in Westmorland County.

FOREWORD

More than half a century ago, W.C. Gussow produced his landmark report on the Carboniferous stratigraphy and structural geology of New Brunswick. Since that time, a number of geologists have investigated Carboniferous rocks in the region. But until the release of the current memoir, *Stratigraphy and Structural History of the Late Paleozoic Maritimes Basin in Southeastern New Brunswick, Canada*, nc single publication had approached the scope and breadth of Gussow's earlier work.

The publication of Memoir 3 represents the completion of a key component of the National Geoscience Mapping Program (NATMAP) in Atlantic Canada. Natural Resources Canada introduced NATMAP in 1992 to increase and enhance geoscientific mapping across Canada through federal, provincial, territorial, and university joint ventures. NATMAP research in Atlantic Canada was conducted under the Magdalen Basin Project, a five-year (1993–1998) study to advance geoscientific knowledge of the onshore late Paleozoic rocks of the composite Maritimes Basin. The New Brunswick component of this joint federal–provincial project was undertaken by the authors of the current memoir, Clint St. Peter and Susan Johnson.

The senior author, Clint St. Peter, hydrocarbon geologist with the Geological Surveys Branch (GSB), New Brunswick Department of Natural Resources, conducted his investigations of the Maritimes Basin in New Brunswick from 1982 until his retirement in 2008. The quality of this report owes much to his meticulous deciphering of the complex stratigraphic relationships within the Maritimes Basin, not only in the area covered by the NATMAP report but also throughout southern New Brunswick. Co-author Susan Johnson, also with GSB, mapped the Late Carboniferous rocks in the NATMAP area of southeastern New Brunswick between 1994 and 1997. Her insights have helped to expand our knowledge of Late Carboniferous stratigraphy across Atlantic Canada.

Memoir 3 integrates new geoscientific and geotechnical information from surface bedrock mapping, borehole logs, seismic surveys, and palynological analyses to create a comprehensive synthesis of the stratigraphy and tectonic evolution of the Maritimes Basin in southeastern New Brunswick. Much of the geotechnical information was the result of renewed hydrocarbon exploration in the Maritimes Basin following the discovery of natural gas in the McCully Field near Sussex in 2000. The report includes six newly revised 1:50 000-scale bedrock geology maps and nearly 100 illustrations.

The geoscientific findings in this memoir not only represent a major contribution to the NATMAP project in Atlantic Canada but also serve as a testament to the continued cooperation between Natural Resources Canada and New Brunswick Department of Natural Resources. As with Gussow's earlier report, this comprehensive publication will become required reading for generations of geoscientists seeking to appreciate the challenging geology of the Maritimes Basin in New Brunswick and the rest of Atlantic Canada.

Les Fyffe*, Director, Geological Surveys Branch, New Brunswick Department of Natural Resources;*
Peter Giles*, Geological Survey of Canada (Atlantic) and* ***Gregory Lynch****, Geological Survey of*
Canada (Québec): co-leaders, NATMAP Magdalen Basin Project, Natural Resources Canada

ABSTRACT

The late Paleozoic Maritimes Basin of eastern Canada is a postorogenic molasse basin that lies partly onland and partly offshore in the Gulf of St. Lawrence. Within the larger basin are smaller (typically less than 4000 km^2) fault-controlled depocentres or subbasins, four of which are entirely or partly located in southeastern New Brunswick. From northwest to southeast the subbasins are Cocagne, Moncton, Sackville, and Cumberland. The sediment fill in each subbasin is mainly terrestrial and up to 6 km thick.

Stratigraphic successions vary somewhat from one subbasin to another but show sufficient regional similarity to be divisible into six disconformity–unconformity-bounded groups. The groups are defined on the bases of their contact relationships, distinctive lithological content, and age, the last of which is supportid by a robust palynological dataset comprising more than 500 assemblages. The groups from oldest to youngest are Horton (Famennian to middle Tournaisian), Sussex (new name, latest middle to late Tournaisian), Windsor (partly marine, early to middle Visean), Mabou (middle Visean to early Namurian), Cumberland (late Yeadonian to early Duckmantian), and Pictou (late Duckmantian to Stephanian).

Significant changes to previous stratigraphic interpretations in southeastern New Brunswick are defended herein with evidence from extensive field mapping, provenance studies, and hundreds of palynological assemblages. Newly defined formations are the McQuade Brook, Steeves Mills, and Indian Mountain formations of the Horton Group; the Stilesville, Briggs Cross, and Ridge Brook formations of the Sussex Group; and the Hopewell Cape Formation of the Mabou Group. The Round Hill, Gautreau, and Weldon formations are reassigned herein from the Horton Group to the Sussex Group; the Grande Anse Formation is reassigned from the Pictou Group to the Cumberland Group. New, formally named members are the Dorchester Cape Member of the Hopewell Cape Formation (Mabou Group), the Chignecto Bay, Breau Creek, Ward Point, and Cole Point members of the Boss Point Formation (Cumberland Group), and the Colpitts Settlement Member of the Salisbury Formation (Pictou Group). The Pugwash Mine and Lime-kiln Brook formations of the Windsor Group in the Cumberland Subbasin of Nova Scotia are recognized in the Cumberland and Sackville subbasins of New Brunswick.

The Horton, Sussex, and Mabou groups are dominated by redbeds, which are locally sourced from crystalline uplifts that flank the subbasins. The redbeds in each group are divided into 1) coarse proximal formations that typically have a wedge-shaped geometry, and 2) fine distal formations with a more lenticular external form. Two notable formations, not redbeds, are the grey lacustrine oil shale-, oil-, and gas-bearing Albert Formation (Horton Group), and the grey playa salt-bearing Gautreau Formation (Sussex Group).

The Mabou Group and older locally sourced immature formations that fill the subbasins are unconformably overlain by the Cumberland Group and succeeding Pictou Group. The base of the Cumberland Group is a fundamental unconformity — the Mississippian–Pennsylvanian break — and marks a significant change in the architecture of the Maritimes Basin in southeastern New Brunswick from its small, multiple, fault-bounded subbasins to a regional subsidence or sag structure. This is reflected by an increase in textural and compositional maturity of the sandstones, and in the widely distributed and tabular shapes of the distantly sourced fluvial formations of the Cumberland and Pictou groups.

The fault zones that define the boundaries of the Cocagne, Moncton, Sackville, and Cumberland subbasins are of two contrasting types. Some faults approximate the original depositional margin of those subbasins. Faults of this type include the basement-flanking Belleisle, Gordon Falls, Caledonia, Wilson Brook, and Harvey–Hopewell faults, all of which have associated basinward, coarse alluvial wedges of Horton, Sussex, and/or Mabou sediments. These faults also underwent postdepositional periods of compressional or transpressional reactivation that facilitated basin inversions. Other basin-bounding faults are more obviously postdepositional and represent structural boundaries associated with one or more inversions of the sedimentary fill within the subbasins. Basin-bounding structures of this type include the North River, Wood Creek, and Shepody–Beckwith faults. The Late Carboniferous and final inversion of the basin fill within the Cumberland and Sackville subbasins was facilitated by decoupling of the Late Carboniferous succession above décollement surfaces at the level of evaporites of the Windsor Group.

The Albert Formation of the Horton Group is host to a petroleum system. Oil and natural gas were produced from the Stoney Creek Field from 1910 to 1991. Two new horizontal wells and several reclaimed shut-in vertical wells have brought a resumption in oil production in 2007. The Albert Formation is also currently being assessed for shale gas and oil shale potential. Copper mineralization occurs in grey sandstones of the Shepody and Boss Point formations. A small copper mine operated in the Boss Point beds at Dorchester in the late 1800s and early 1900s; it, along with several other base-metal sulphide occurrences in the area, is being actively evaluated. There is also a resurgence in uranium exploration in the Maritimes Basin in New Brunswick. In southeastern New Brunswick, the main targets are lacustrine rocks of the Horton Group, the unconformity at the base of the Sussex Group, and potential roll-fronts in the grey strata of the Mabou, Cumberland and Pictou groups.

RÉSUMÉ

Le bassin du Paléozoïque tardif des Maritimes dans l'Est du Canada est un bassin molassique postorogénique situé en partie en milieu terrestre et en partie au large à l'intérieur du golfe du Saint-Laurent. Des zones de dépôt maximum ou sous-bassins contrôlés par des failles plus modestes (ayant habituellement moins de 4 000 kilomètres carrés) se trouvent à l'intérieur du bassin de superficie supérieure, et quatre d'entre elles sont situées entièrement ou en partie dans le Sud-Est du Nouveau-Brunswick. Ces sous-bassins comprennent, du nord-ouest au sud-est, ceux de Cocagne, de Moncton, de Sackville et de Cumberland. Le remblai sédimentaire de chaque sous-bassin est essentiellement terrestre et a jusqu'à six kilomètres d'épaisseur.

Les successions stratigraphiques varient légèrement d'un sous-bassin à l'autre, mais présentent une similarité régionale suffisante pour qu'on puisse les subdiviser en six groupes délimités par des discordances. On a défini les groupes en fonction de leurs liens de contact, de leur teneur lithologique distinctive et de leur âge, lequel repose sur un ensemble de données palynologiques robustes comportant plus de 500 assemblages. Les groupes établis comprennent, du plus âgé au plus récent, ceux de Horton (Famennien à Tournaisien moyen), de Sussex (nouveau nom, Tournaisien moyen tardif à tardif), de Windsor (en partie marin, Viséen précoce à moyen), de Mabou (Viséen moyen à Namurien précoce), de Cumberland (Yeadonien tardif à Duckmantien précoce) et de Pictou (Duckmantien tardif à Stéphanien).

Les présentes recommandent des changements importants aux interprétations stratigraphiques antérieures dans le Sud-Est du Nouveau-Brunswick en s'appuyant sur les preuves de travaux cartographiques sur le terrain poussés, d'études de la provenance et de centaines d'assemblages palynologiques. Les nouvelles formations définies incluent les formations de McQuade Brook, de Steeves Mills et d'Indian Mountain du groupe de Horton, les formations de Stilesville, de Briggs Cross et de Ridge Brook du groupe de Sussex, et la Formation de Hopewell Cape du groupe de Mabou. On rattache désormais les formations de Round Hill, de Gautreau, et de Weldon au groupe de Sussex plutôt qu'à celui de Horton et on rattache la Formation de Grande Anse au groupe de Cumberland au lieu de celui de Pictou. Les nouveaux membres officiellement baptisés comprennent les membres du cap Dorchester de la Formation de Hopewell Cape (groupe de Mabou), les membres de la baie Chignectou, de la crique Breau, de la pointe Ward et de la pointe Cole de la Formation de Boss Point (groupe de Cumberland) et le membre de Colpitts Settlement de la Formation de Salisbury (groupe de Pictou). On reconnaît les

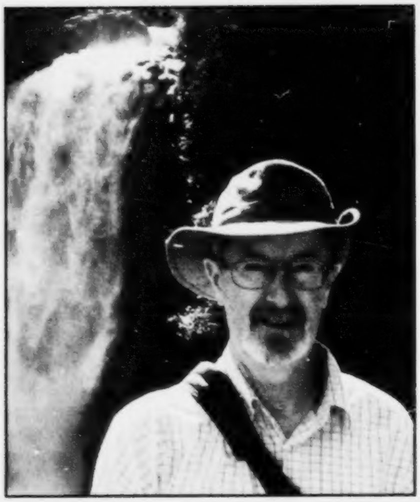
formations de Pugwash Mine et de Lime-kiln Brook du groupe de Windsor dans le sous-bassin de Cumberland en Nouvelle-Écosse à l'intérieur des sous-bassins de Cumberland et de Sackville au Nouveau-Brunswick.

Les couches rouges provenant localement de soulèvements cristallins bordant les sous-bassins prédominent dans les groupes de Horton, de Sussex et de Mabou. Les couches rouges se répartissent dans chaque groupe en 1) formations proximales grossières ayant généralement une géométrie cunéiforme et en 2) formations distales fines d'une forme externe plus lenticulaire. Deux formations notables, ne constituant pas des couches rouges, sont la formation lacustre grise renfermant des schistes bitumineux, du pétrole et du gaz naturel d'Albert (groupe de Horton) et la Formation salinifère à bassin de sel grise de Gautreau (groupe de Sussex).

Le groupe de Mabou et les formations immatures d'origine locale plus anciennes qui remplissent les sous-bassins sont recouvertes de façon non concordante par le groupe de Cumberland et le groupe subséquent de Pictou. La base du groupe de Cumberland est une discordance fondamentale : la lacune stratigraphique séparant le Mississippien et le Pennsylvanien; elle marque un changement marqué dans l'architecture du bassin des Maritimes dans le Sud-Est du Nouveau-Brunswick, qui passe de multiples petits bassins délimités par des failles à une structure d'affaissement ou d'enfoncement d'envergure régionale. La transformation transparaît dans un accroissement de la maturité de la texture et de la composition des grès ainsi que dans les formes tabulaires et répandues des formations fluviatiles d'origine lointaine des groupes de Cumberland et de Pictou.

Les zones faillées qui définissent les limites des sous-bassins de Cocagne, de Moncton, de Sackville et de Cumberland se répartissent en deux types opposés. Certaines failles correspondent approximativement à la limite sédimentaire originale de ces sous-bassins. Les failles de ce genre comprennent les failles latérales au fond de Belleisle, des chutes Gordon, de Caledonia, du ruisseau Wilson et de Harvey–Hopewell, auxquelles sont toutes associés des cônes alluviaux grossiers vers l'intérieur du bassin de sédiments de Horton, de Sussex ou de Mabou. Ces failles ont également subi des périodes postsédimentaires de réactivation de compression ou de transpression qui ont facilité les inversions des bassins. D'autres failles délimitant des bassins sont plus nettement postsédimentaires et représentent les limites structurales associées à une ou plusieurs inversions du remblai sédimentaire à l'intérieur des sous-bassins. Les structures délimitant les bassins de ce type comprennent les failles de la rivière North, de la crique Wood et de Shepody–Beckwith. L'inversion du Carbonifère tardif et finale du remblai du bassin à l'intérieur des sous-bassins de Cumberland et de Sackville a été facilitée par le découplage de la succession du Carbonifère tardif au-dessus des surfaces de décollement au niveau des évaporites du groupe de Windsor.

La Formation d'Albert du groupe de Horton abrite un système pétrolifère. On a produit du pétrole et du gaz naturel du champ de Stoney Creek de 1910 à 1991. La production pétrolière a repris en 2007 grâce à deux nouveaux puits horizontaux et plusieurs puits verticaux inexploités réaménagés. On est par ailleurs actuellement en train d'évaluer le potentiel en gaz de schiste et en schiste bitumineux de la Formation d'Albert. Une minéralisation de cuivre est présente dans les grès gris des formations de Shepody et de Boss Point. Une petite mine de cuivre a été exploitée dans les couches de Boss Point de Dorchester vers la fin des années 1800 et au début des années 1900. On est présentement en train d'évaluer activement celle-ci ainsi que plusieurs autres venues de sulfures de métaux communs dans le secteur. Nous assistons à une relance de l'exploration de l'uranium dans le bassin des Maritimes au Nouveau-Brunswick. Dans le Sud-Est du Nouveau-Brunswick, les principales cibles sont les roches lacustres du groupe de Horton, la discordance à la base du groupe de Sussex et des fronts de minéralisation possibles dans les strates grises des groupes de Mabou, de Cumberland et de Pictou.



Clint St. Peter was born in Victoria County, New Brunswick. He attended University of New Brunswick in Fredericton and received a B.Sc. in Geology in 1972. Clint returned to UNB as a part-time student and in 1992 completed his M.Sc. with a thesis in stratigraphy and structural geology. Clint worked his entire professional career with New Brunswick Department of Natural Resources. He retired from the government in 2008 after 37 years of service. For the last 25 years of his tenure he studied the Carboniferous rocks of New Brunswick. The emphasis of this work was on lithostratigraphy, structural synthesis, and the architecture of small terrestrial basins. Throughout those years Clint was actively involved with the growth of petroleum exploration and development in the Moncton Subbasin. Since retiring from NBDNR he has started a sole-proprietorship geological consulting business called RockQuest Consulting.

Frederick Brook flowing over outcrops of red, flat-bedded conglomerates of the Early Carboniferous Hillsborough Formation near Albert Mines, southeastern New Brunswick.

Susan Johnson graduated with a B.Sc. in Geology from Acadia University in 1981 and spent the early part of her career working in uranium exploration and at the Mount Pleasant tungsten mine. In 1986 she joined New Brunswick Department of Natural Resources in Sussex and has since worked as an NBDNR bedrock mapping geologist in southern New Brunswick. She has focused mainly on the stratigraphy and geochemistry of Neoproterozoic to Carboniferous rocks. Susan has been active in the Atlantic Geoscience Society for many years, serving as past-president and councillor, and receiving their Distinguished Service Award in 2007. She is also a member of the Association of Professional Engineers and Geoscientists of New Brunswick, and of the Atlantic Provinces Council on the Sciences, Earth Sciences Committee. She is currently Assistant Regional Geologist for southern New Brunswick.

CHAPTER 1

THE MARITIMES BASIN OF SOUTHEASTERN NEW BRUNSWICK

INTRODUCTION

Scope of Report

This report presents a summary of stratigraphic observations and interpretations for the Late Devonian–Early Permian strata in NTS quadrangles 11 L/04 (Tormentine), 21 H/10 (Alma), 21 H/15 (Hillsborough), 21 H/16 (Amherst), 21 I/ 01 (Port Elgin), and 21 I/02 (Moncton) in southeastern New Brunswick (Fig. 1). The information contained herein has resulted largely from 1) geological studies conducted between 1982 and 2007 by Clint St. Peter (CSP) of New Brunswick Department of Natural Resources (NBDNR) before and subsequent to the National Mapping Program (NATMAP) of the Geological Survey of Canada (GSC), and 2) bedrock mapping undertaken from 1994 to 1997 by Susan Johnson (SCJ) of NBDNR under NATMAP.

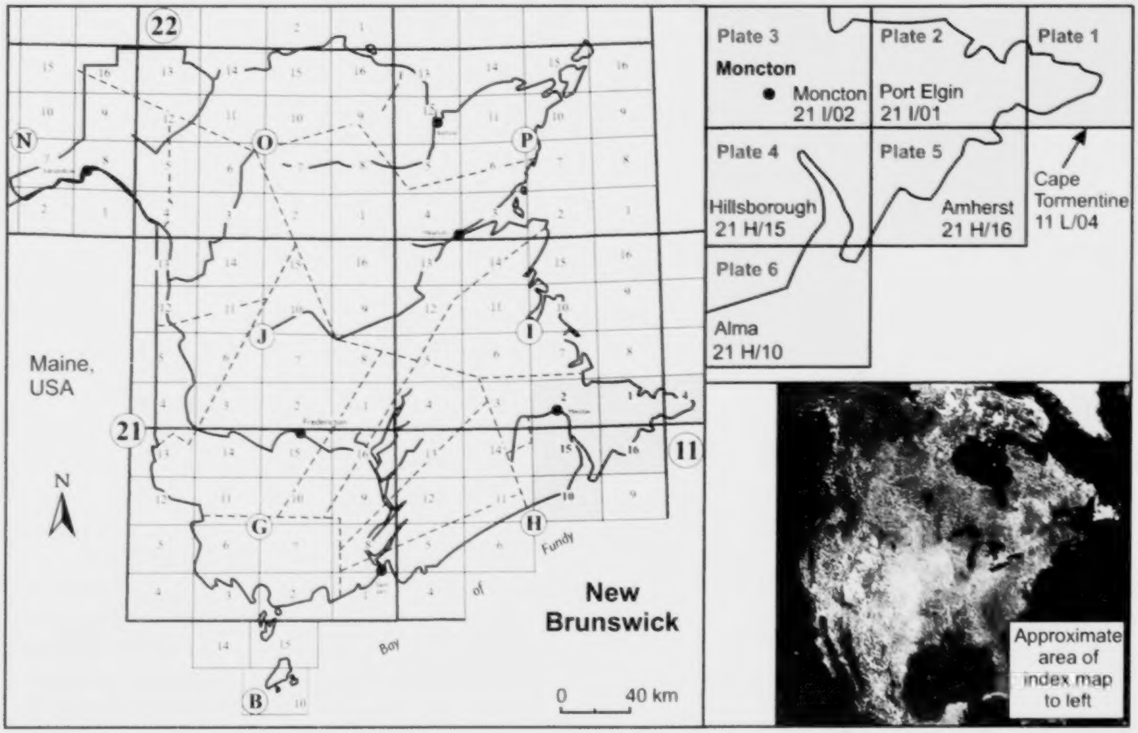

22
N
O
P
J
I
21
11
G
H
B
Maine,
USA
N
Fundy
of
Bay
New
Brunswick
0
40 km
Plate 3
Moncton
Moncton
21 I/02
Plate 2
Port Elgin
21 I/01
Plate 1
Plate 4
Hillsborough
21 H/15
Plate 5
Amherst
21 H/16
Cape
Tormentine
11 L/04
Plate 6
Alma
21 H/10
Approximate
area of
index map
to left

Figure 1. Index map showing NTS quadrants covered by the report area in southeastern New Brunswick. Upper inset shows the location of Plates 1 to 6 that accompany this report.

Prior to the present study, regional mapping at the scale of 1 inch to 1 mile existed for the Alma (Flaherty and Norman 1941), Hillsborough (Wright 1922; Norman 1941a), and Moncton (Norman 1941b; Carr 1968) quadrangles. The only geological synthesis of the entire area was provided by Gussow (1953) and was based on a regional mapping project by Shell Oil Company of Canada Limited. After Gussow's work, no significant mapping took place in the area until the publication of 1 inch to ¼ mile-scale provincial maps for the Hillsborough and

Dorchester areas (McLeod and Ruitenberg 1978; McLeod 1980). Following their work, and before commencement of the Magdalen Basin NATMAP project, provincially funded mapping studies were restricted mainly to the Hillsborough and Moncton quadrangles (Fig. 1). They consisted of 1) 1:20 000-scale bedrock mapping of the Albert Formation (St. Peter 1989a, 1989b), 2) 1:20 000-scale mapping of the Horton Group in the Indian Mountain area (St. Peter 1995a–1995c), and 3) 1:20 000-scale mapping of the Mabou and Cumberland groups in the Alma and Hillsborough map areas (St. Peter 1996a–1996e; St. Peter and Johnson 1996).

The current report is primarily a description of field-based observations and interpretations. The purposes of the report are 1) to describe the late Paleozoic lithostratigraphy of the Maritimes Basin of southeastern New Brunswick with particular emphasis on the evidence for significant revisions to the terrestrial clastic lithostratigraphy in the Horton, Sussex (new name in New Brunswick), Mabou (new name in New Brunswick), Cumberland, and Pictou groups, 2) to reassess the age and biostratigraphic significance of new miospore assemblages that were recovered from the succession and are relevant to the proposed stratigraphic revisions, 3) to provide a summary of the main structural features (faults, folds, unconformities, salt diapirism) responsible for and resulting from the inception, subsidence, and inversion of the Cocagne, Moncton, Sackville, and Cumberland subbasins, and 4) to briefly describe energy and mineral resources of the late Paleozoic rocks in the context of the stratigraphic and structural revisions.

Notes for Readers

Map Plates: Details of the bedrock geology discussed in this report are compiled on six 1:50 000-scale bedrock geology maps. The maps are referred to herein as Plates 1 to 6 (Fig. 2) and are available on the accompanying CD-ROM. They were originally published as Johnson (2008a), Johnson (2008b), Johnson and St. Peter (2008), St. Peter and Johnson (2008), Johnson (2008c), and St. Peter (2008), respectively.

Figure 3 in this chapter shows most (although not all) of the geographical place names cited in the report. The figure includes the map plate boundaries to facilitate cross-referencing. Rather than constantly citing Figure 3 throughout the text, the authors assume that the interested reader will check the figure whenever geographical 'navigation' is required. Map plate citations are provided when a closer examination of the bedrock geology would augment the text or help to fully appreciate the geological point being made.

Rock Classification Terminology: The term 'sandstone' is used in this report to denote fairly immature sandstones. 'Arenite' is used to denote mineralogically mature (i.e., quartz-rich) or texturally mature (i.e., well-rounded grains and matrix-poor) sandstones.

Well Citations: The locations of most hydrocarbon boreholes drilled in the report area since the early 1900s are plotted on Plates 1 to 6 according to their Unique Identification (UI) three-digit code (e.g., Well 190). Appendix 1 lists all wells cited in the report, giving the UI number, company name and well number, related map plate, and approximate location on that map plate (e.g., 2 km east of Rosevale). The New Brunswick Department of Natural Resources (NBDNR) Borehole Database (NBDNR 2004) contains further information on each well. In addition, lithologs for many of the wells are stored at NBDNR Fredericton.

Palynological Data: The localities of palynological assemblages cited in this report are plotted on Plates 1 to 6, and their numbers are summarized in Table 3. A detailed compilation of the palynological data appears in St. Peter and Johnson (2009). In that compilation, each assemblage has a *spore reference code* that relates to a locality on one of the six map plates. The code is either numeric or alphanumeric.

- A *numeric code* applies where a single sample with its accompanying assemblage has been reported at a locality. The numeric codes are arranged from **1** (oldest) in the Memramcook Formation to **185** (youngest) in the Richibucto Formation on both the map plates and in St. Peter and Johnson (2009).

- An *alphanumeric code* applies where 1) more than one sample is reported from the same locality, or 2) more than one palynological report is available for the same sample at a locality, or 3) more than one sample exists in a formation in an area where samples are too closely spaced to be marked clearly on Plates 1 to 6. The alphanumeric codes are arranged from **A** (oldest) in the Memramcook Formation to **CV** (youngest) in the Richibucto Formation. Alphanumeric citations in St. Peter and Johnson (2009) give the full code (e.g., **A1, A2, A3**, etc.). Their correlative codes on the map plates show the alphabetic but not the numeric part of the code (e.g., map plate shows **A** but not **A1, A2, A3**, etc.).

LOCATION, PHYSIOGRAPHY, AND ACCESS

The area of this report comprises about 3300 km^2 in southeastern New Brunswick, eastern Canada (Fig. 1, 2). It includes all regions underlain by late Paleozoic strata in NTS quadrangles 21 H/10, 21 H/15, 21 H/16, 21 I/01, 21 I/02, and 11 L/04. The report area, approximately triangular, is bounded on the north by latitude 46°15'N and Northumberland Strait, on the west by longitude 65°00'W, and on the southeast by Chignecto Bay, Cumberland Basin, and the New Brunswick–Nova Scotia border.

Southeastern New Brunswick encompasses two main physiographic divisions, those being the Caledonian Highlands and the New Brunswick Lowlands (Fig. 2; Rampton et al. 1984). The highlands have a northeast-trending core called the Central Plateau that straddles the Alma and Hillsborough NTS quadrangles (Fig. 2). The mountainous plateau is founded mainly on hard, deformed crystalline volcanic and plutonic rocks of Neoproterozoic age and forms a series of prominent hills with elevations of up to 400 m. The plateau topography is characterized by deeply incised streams that drain southward to Chignecto Bay and northward to Petitcodiac River.

The Central Plateau is flanked on the northwest by the Anagance Ridges and on the southeast by the Shepody Ridges (Fig. 2). The ridges form a series of northeast-trending, low-relief, rounded hills with elevations of less than 300 m. The ridges are supported by moderately to steeply dipping Early Carboniferous strata of the Horton, Sussex, Windsor, and Mabou groups. The Central Plateau falls away to the northeast, forming physiographic subdivisions that lie adjacent to the Petitcodiac and Memramcook rivers and that Rampton et al. (1984) label as Moncton Basin and Dorchester Upland (Fig. 2). The Moncton Basin is underlain by flat-lying sandstones and shales of the Cumberland and Pictou groups. The Dorchester Upland is founded on a patchwork of variously dipping clastics and minor

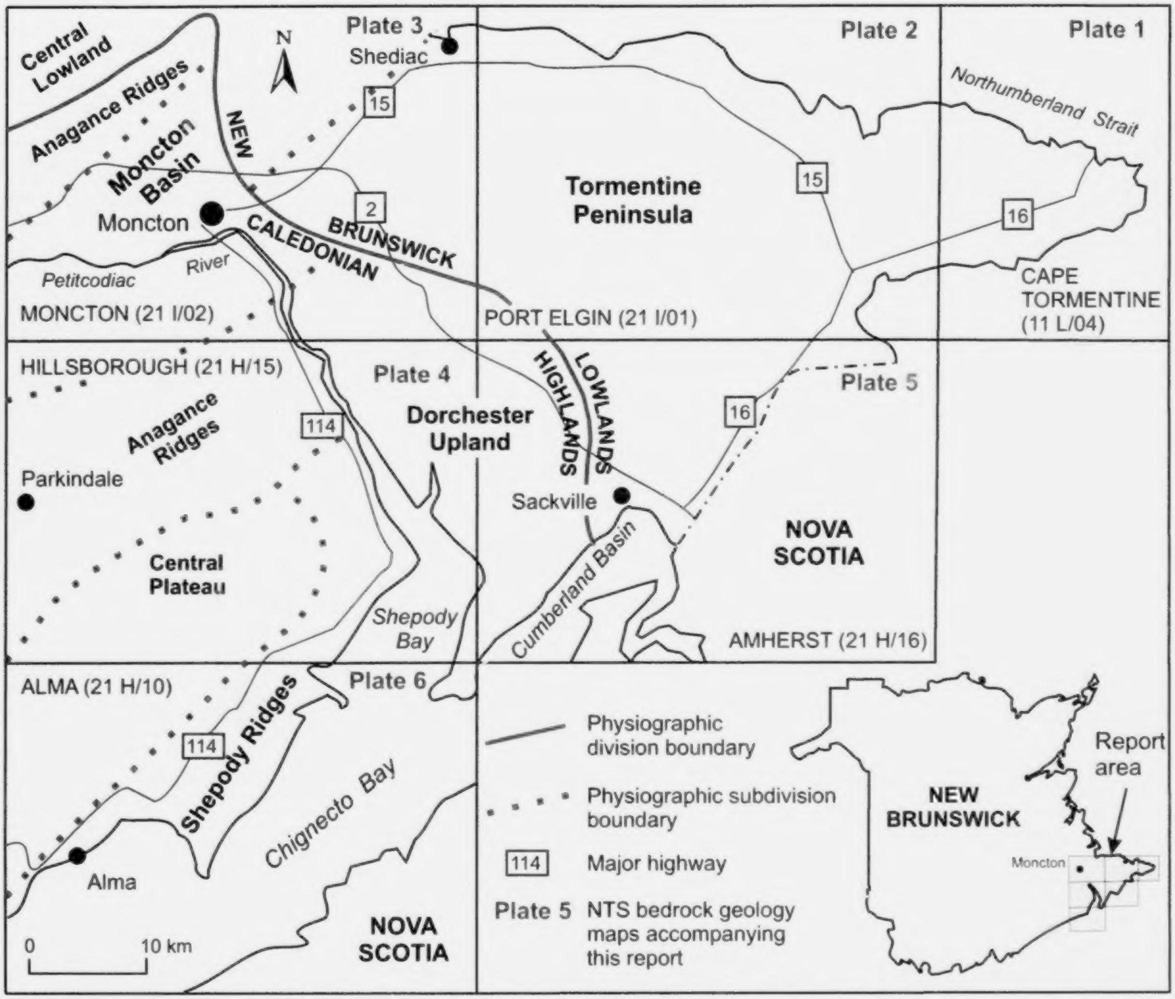

Central Lowland
Anagance Ridges
Moncton Basin
NEW BRUNSWICK CALEDONIAN
Plate 3
Shediac
N
15
2
Moncton
Petitcodiac River
MONCTON (21 I/02)
Plate 2
Plate 1
Northumberland Strait
Tormentine Peninsula
15
16
CAPE TORMENTINE (11 L/04)
PORT ELGIN (21 I/01)
HILLSBOROUGH (21 H/15)
Plate 4
Anagance Ridges
Parkindale
114
Dorchester Upland
LOWLANDS
HIGHLANDS
Sackville
Plate 5
16
NOVA SCOTIA
Central Plateau
Shepody Bay
Cumberland Basin
AMHERST (21 H/16)
ALMA (21 H/10)
Plate 6
114
Shepody Ridges
Chignecto Bay
Alma
NOVA SCOTIA
0
10 km
Physiographic division boundary
Physiographic subdivision boundary
114 Major highway
Plate 5 NTS bedrock geology maps accompanying this report
NEW BRUNSWICK
Report area
Moncton

Figure 2. Main physiographic features of southeastern New Brunswick, modified after Rampton et al. (1984).

carbonate and sulphate strata of the Horton, Sussex, Windsor, Mabou, and Cumberland groups.

The New Brunswick Lowlands contain two physiographic subdivisions: the Central Lowland and the Tormentine Peninsula (Fig. 2). In the report area the Central Lowland forms a broad, swampy, poorly drained, low-relief plain underlain by flat-lying sandstones and shales of the Pictou Group. The Tormentine Peninsula is also characterized by low, swampy topography except in the southeast adjacent to the New Brunswick–Nova Scotia border, where a northeast-trending ridge with an elevation of less than 50 m is supported by moderately to steeply dipping sandstones and conglomerates of the Cumberland Group.

Highway access in southeastern New Brunswick is excellent. The Trans-Canada Highway (Highway 2) traverses the area from west of Moncton through Sackville to the provincial border with Nova Scotia (Fig. 2). Major secondary roads include Highway 114 that leads south from Moncton along the west side of Petitcodiac River to Fundy National Park, Highway 16 that leads northeast from Highway 2 near Sackville to Cape Tormentine, and Highway 15 that runs from Moncton to Shediac and Northumberland Strait (Fig. 2). Numerous paved and gravel tertiary roads allow local access. The main line of the Canadian National (CN) railway between Halifax and Montreal passes through Sackville and Moncton before crossing New Brunswick and entering Québec. An international airport services Moncton.

REGIONAL GEOLOGY

The Late Devonian–Early Permian stratified rocks in Atlantic Canada were deposited in a large post-Acadian successor basin called the Maritimes Basin (Fig. 4; Roliff 1962). The Maritimes Basin forms a cover sequence resting on pre-Late Devonian crystalline basement terranes that constitute the northeastern end of the Appalachian Orogen. These terranes form the foundation of the northeastern Appalachian mountain chain and comprise rocks ranging from Proterozoic Grenville gneiss to Middle Devonian plutonic, volcanic, and sedimentary rocks.

Pre-Late Devonian Crystalline Basement

Tectonostratigraphic Divisions

Several tectonic overviews of the geology of the northeastern Appalachian Orogen have been published since the 1960s (Wilson 1966; Bird and Dewey 1970; Williams 1978, 1979; Williams and Hatcher 1982; Rast 1984, 1989; Stockmal et al. 1987; Williams et al. 1988; Barr et al. 1998; van Staal et al. 1998). These overviews introduced and developed a revolutionary model that explained the Appalachian Orogen as the product of opening and closing of the late Proterozoic to early Paleozoic Iapetus Ocean. The various authors divided the Ordovician and older basement rocks of the northeastern Appalachians into several tectonostratigraphic zones or terranes on the basis of the distinctive age and spatial distribution of characteristic rock types, paleomagnetic records, and faunal provinciality.

Since the mid-1990s, geoscientists have made many advances in elucidating the architecture of the northeastern Appalachian Orogen through such work as amassing new radiometric dates, undertaking geochemical studies of volcanic and plutonic suites, and refining the placement of boundaries (faults) that clarify geotectonic relationships among the tectonostratigraphic zones. Probably the most important contributions have come from studies relating the evolution of arc and back-arc basins to the Laurentia and Gondwanan margins of the Iapetus Ocean. Figure 5 shows the various tectonostratigraphic divisions as they are currently defined and designated. Further details for the interested reader are provided in van Staal and Fyffe (1995a, 1995b), van Staal et al. (1996, 1998), Hibbard et al. (2006), and van Staal (2007).

The Proterozoic to Devonian basement rocks flooring the Maritimes Basin are transected by several major northeast-trending, long-lived faults (Fig. 6) that have had a profound influence on basin development, sedimentation history, and the subsequent phases of uplift and inversion. Many of these faults (the Belleisle, Caledonia, and Harvey–Hopewell, for example) are basin-bounding structures that have 'compartmentalized' the Maritimes Basin into a number of subbasins and adjoining uplifts or basement blocks.

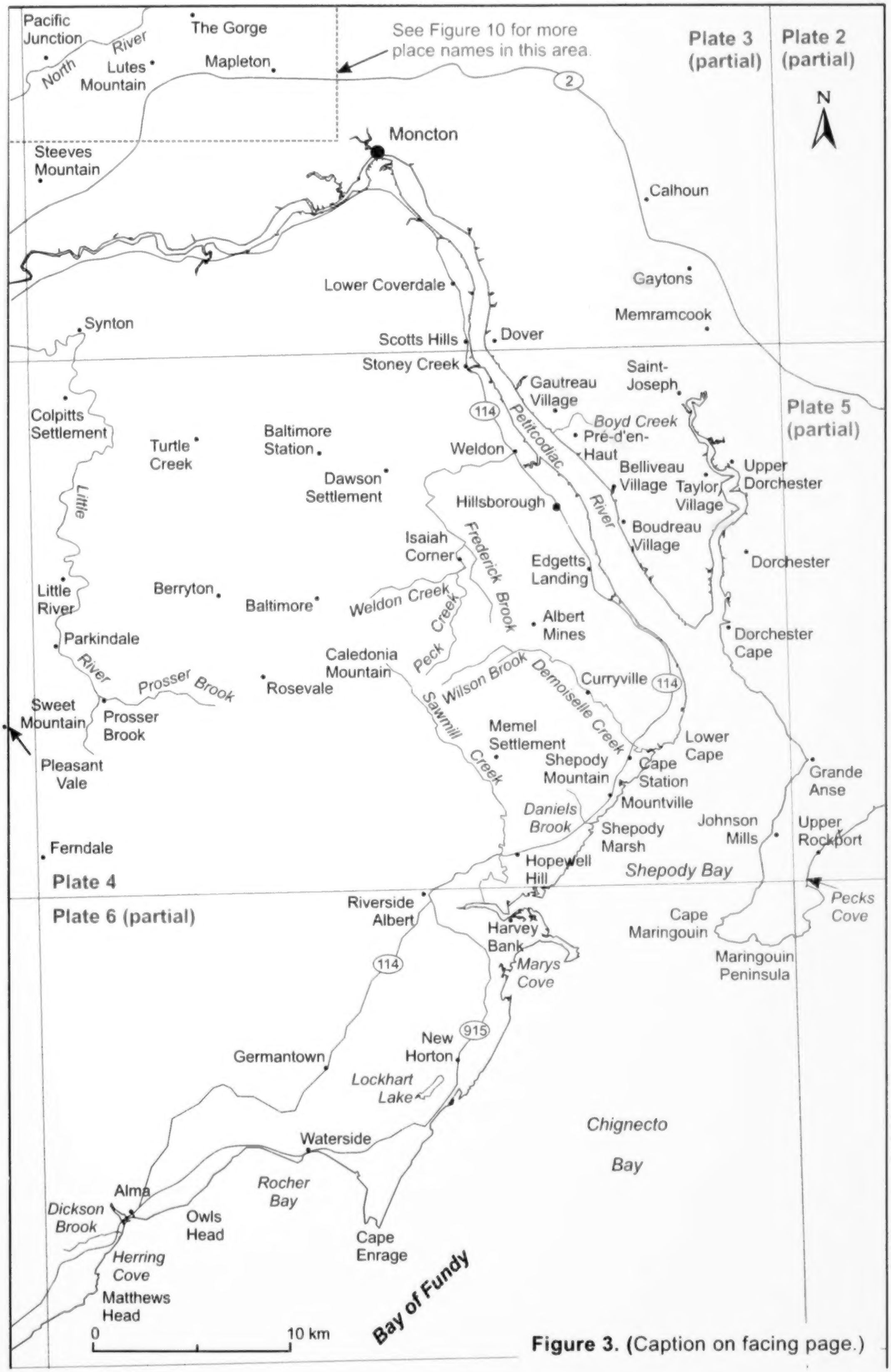

Pacific Junction
North River
The Gorge
Lutes Mountain
Mapleton
See Figure 10 for more place names in this area.
Plate 3 (partial)
Plate 2 (partial)
N
2
Moncton
Steeves Mountain
Calhoun
Gaytons
Lower Coverdale
Memramcook
Synton
Scotts Hills
Dover
Stoney Creek
Saint-Joseph
Gautreau Village
Plate 5 (partial)
114
Colpitts Settlement
Boyd Creek
Pré-d'en-Haut
Turtle Creek
Baltimore Station
Weldon
Petitcodiac River
Upper Dorchester
Belliveau Village
Taylor Village
Dawson Settlement
Hillsborough
Little
Boudreau Village
Isaiah Corner
Frederick Brook
Dorchester
Edgetts Landing
Little River
Berryton
Baltimore
Weldon Creek
Albert Mines
Dorchester Cape
Parkindale
Peck Creek
Caledonia Mountain
River
Prosser Brook
Rosevale
Wilson Brook
Demoiselle Creek
Curryville
114
Sweet Mountain
Prosser Brook
Sawmill Creek
Memel Settlement
Lower Cape
Pleasant Vale
Shepody Mountain
Cape Station
Grande Anse
Mountville
Daniels Brook
Shepody Marsh
Johnson Mills
Upper Rockport
Ferndale
Hopewell Hill
Shepody Bay
Plate 4
Plate 6 (partial)
Riverside Albert
Pecks Cove
Harvey Bank
Cape Maringouin
Marys Cove
114
Maringouin Peninsula
New Horton
915
Germantown
Lockhart Lake
Chignecto Bay
Waterside
Rocher Bay
Alma
Dickson Brook
Owls Head
Cape Enrage
Herring Cove
Matthews Head
Bay of Fundy
0
10 km

Figure 3. (Caption on facing page.)

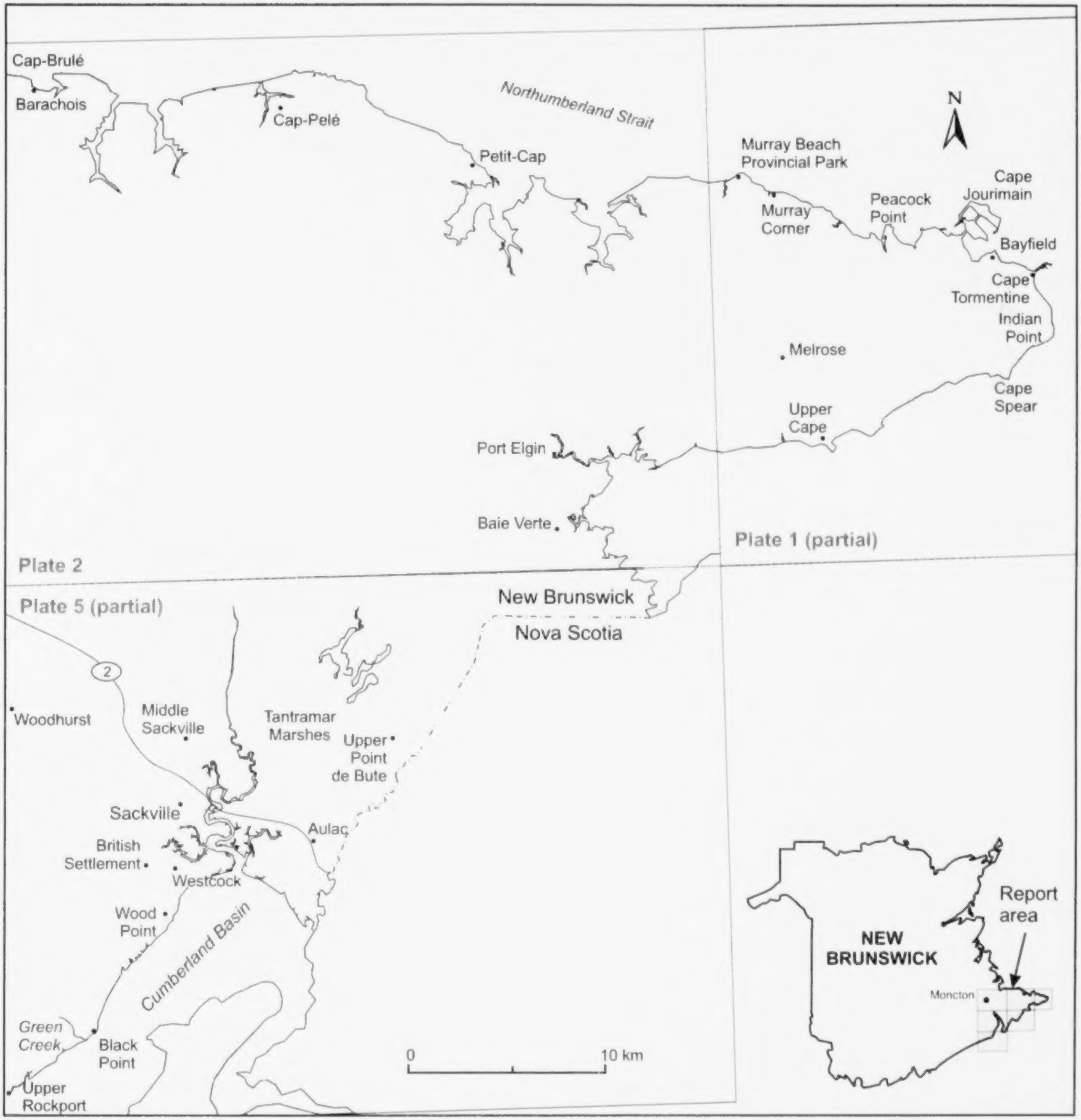

Cap-Brulé
Barachois
Cap-Pelé
Northumberland Strait
Petit-Cap
Murray Beach Provincial Park
Murray Corner
Peacock Point
Cape Jourimain
Bayfield
Cape Tormentine
Indian Point
Melrose
Cape Spear
Upper Cape
Port Elgin
Baie Verte
Plate 1 (partial)
Plate 2
Plate 5 (partial)
New Brunswick
Nova Scotia
2
Woodhurst
Middle Sackville
Tantramar Marshes
Upper Point de Bute
Sackville
Aulac
British Settlement
Westcock
Wood Point
Cumberland Basin
Green Creek
Black Point
Upper Rockport
0
10 km
N
Report area
NEW BRUNSWICK
Moncton

Figure 3. Geographical place names in the report area, as cited in the text. Map on this page continues northeastward from and slightly overlaps (see Upper Rockport) map on the facing page.

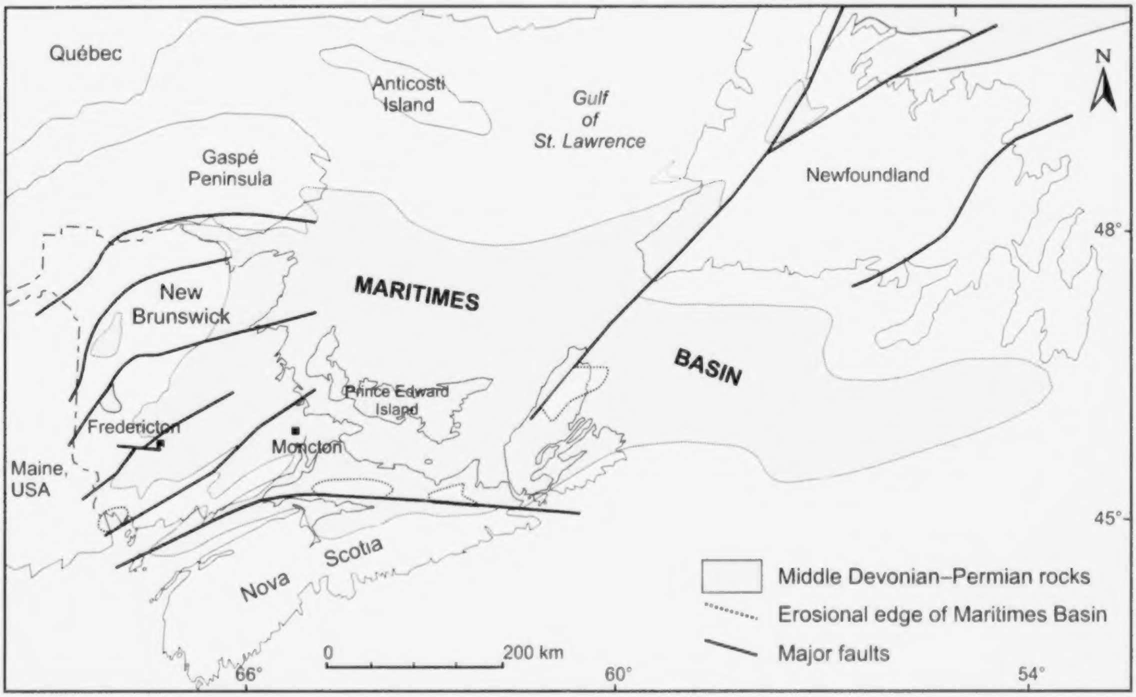

Québec
Anticosti Island
Gulf of St. Lawrence
Gaspé Peninsula
Newfoundland
N
48°
New Brunswick
MARITIMES
BASIN
Prince Edward Island
Fredericton
Moncton
Maine, USA
45°
Nova Scotia
Middle Devonian–Permian rocks
Erosional edge of Maritimes Basin
Major faults
0
200 km
66°
60°
54°

Figure 4. The Maritimes Basin in Atlantic Canada, showing its present erosional edge. (Adapted from Roliff 1962; Williams 1974; Bradley 1982; and Fyffe and Barr 1986.)

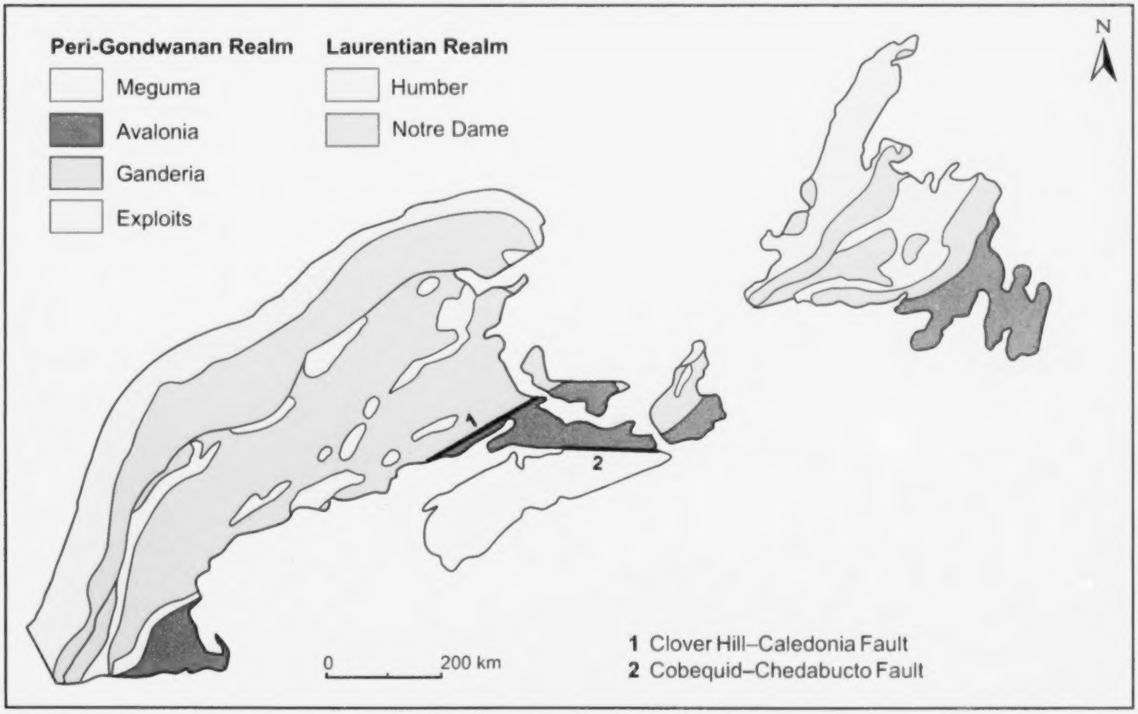

Peri-Gondwanan Realm
Meguma
Avalonia
Ganderia
Exploits
Laurentian Realm
Humber
Notre Dame
N
1
2
0
200 km
1 Clover Hill–Caledonia Fault
2 Cobequid–Chedabucto Fault

Figure 5. Tectonostratigraphic divisions in the Peri-Gondwanan and Laurentian realms of the northern Appalachian Orogen (after Hibbard et al. 2006).

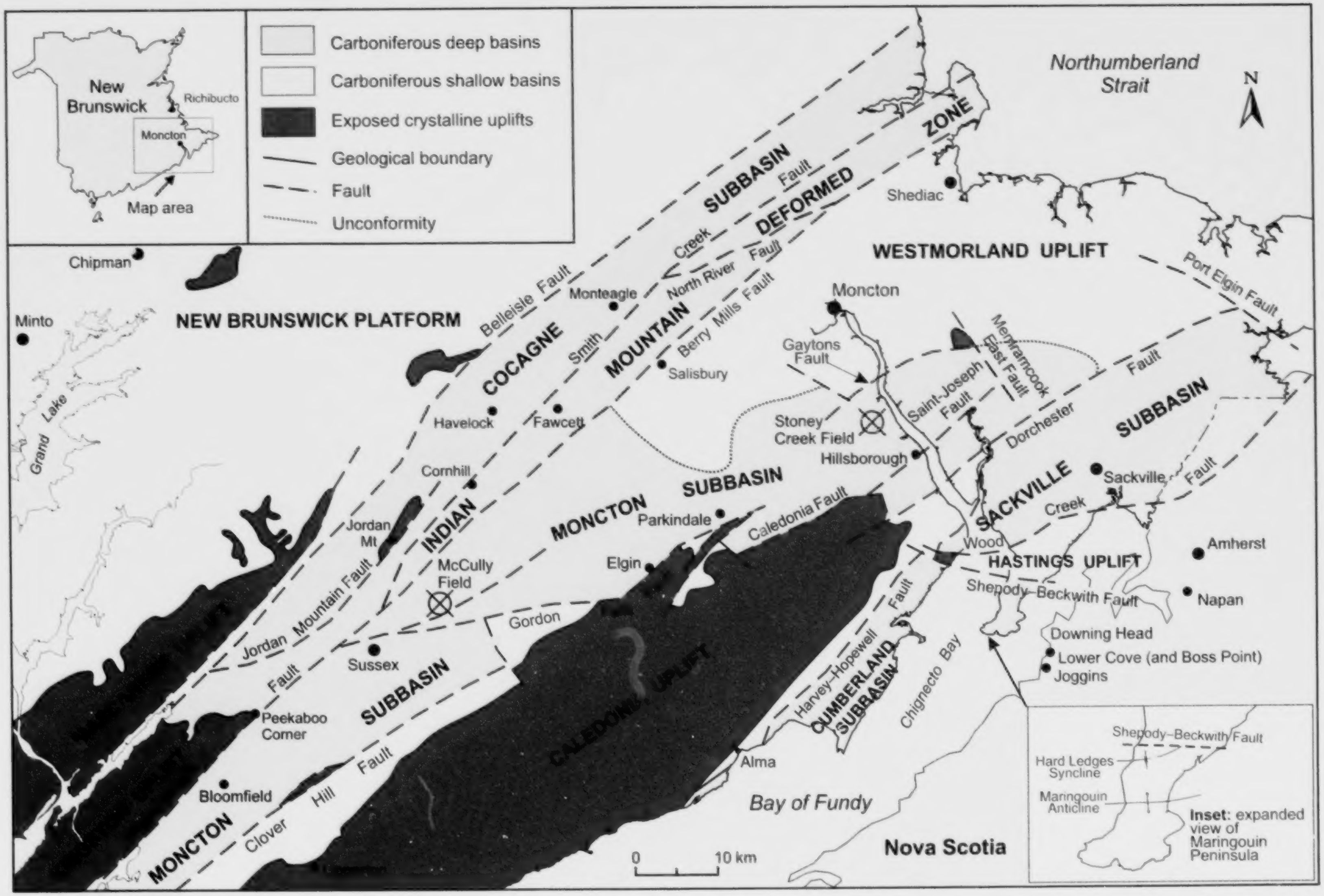

New Brunswick
Richibucto
Moncton
Map area
Carboniferous deep basins
Carboniferous shallow basins
Exposed crystalline uplifts
Geological boundary
Fault
Unconformity
Northumberland Strait
N
Chipman
Minto
NEW BRUNSWICK PLATFORM
Grand Lake
Belleisle Fault
COCAGNE
SUBBASIN
Monteagle
Creek Fault
Smith
MOUNTAIN
DEFORMED
ZONE
North River Fault
Berry Mills Fault
Salisbury
Shediac
WESTMORLAND UPLIFT
Port Elgin Fault
Moncton
Gaytons Fault
Memramcook East Fault
Saint-Joseph Fault
Stoney Creek Field
Hillsborough
Dorchester Fault
SUBBASIN
SACKVILLE
Sackville
Creek
Fault
Havelock
Fawcett
Cornhill
MONCTON SUBBASIN
Parkindale
Caledonia Fault
Jordan Mt
INDIAN
McCully Field
Elgin
Jordan Mountain Fault
Gordon
Sussex
Wood
HASTINGS UPLIFT
Amherst
Shepody–Beckwith Fault
Napan
Downing Head
Lower Cove (and Boss Point)
Joggins
Fault
Harvey–Hopewell
CUMBERLAND SUBBASIN
Chignecto Bay
CALEDONIA UPLIFT
Peekaboo Corner
SUBBASIN
Fault
Bloomfield
Clover Hill Fault
MONCTON
Alma
Bay of Fundy
Nova Scotia
0
10 km
Shepody–Beckwith Fault
Hard Ledges Syncline
Maringouin Anticline
Inset: expanded view of Maringouin Peninsula

Figure 6. Distribution of subbasins and crystalline uplifts in the Maritimes Basin of southeastern New Brunswick. The Hastings Uplift, Westmorland Uplift, and New Brunswick Platform are subsurface basement 'ridges' or blocks overlain by a cover of Late Carboniferous strata. Fault traces on map are projected to surface where they are buried beneath the Mabou unconformity (e.g., Saint-Joseph Fault) or Pictou unconformity (e.g., Dorchester and Port Elgin faults). Map sources are Keppie (1979), Potter et al. (1979), Howie (1986), Martel (1987), St. Peter (1993, 2006a), and Ryan and Boehner (1994).

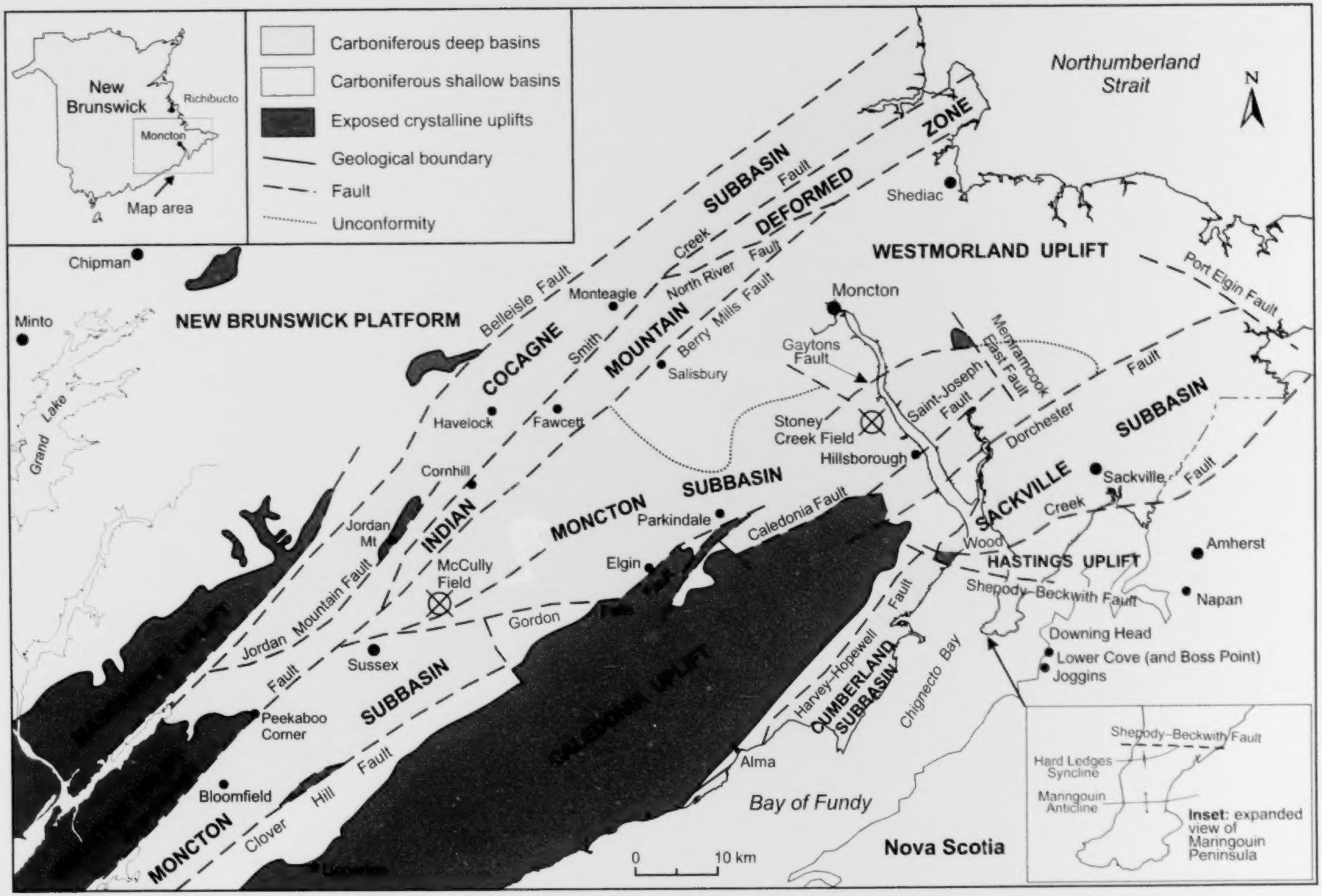

New Brunswick
Richibucto
Moncton
Map area
Carboniferous deep basins
Carboniferous shallow basins
Exposed crystalline uplifts
Geological boundary
Fault
Unconformity
Northumberland Strait
N
ZONE
DEFORMED
SUBBASIN
Fault
Creek
Shediac
WESTMORLAND UPLIFT
Port Elgin Fault
Chipman
North River
Fault
Belleisle Fault
Monteagle
Berry Mills Fault
Moncton
Minto
NEW BRUNSWICK PLATFORM
Smith
MOUNTAIN
COCAGNE
Salisbury
Gaytons Fault
Memramcook East Fault
Saint-Joseph Fault
Fault
Grand Lake
Havelock
Fawcett
Stoney Creek Field
Dorchester
SUBBASIN
Hillsborough
Cornhill
SUBBASIN
SACKVILLE
Sackville
Fault
Creek
INDIAN
MONCTON
Parkindale
Jordan Mt
Caledonia Fault
Wood
HASTINGS UPLIFT
Amherst
McCully Field
Elgin
Shepody–Beckwith Fault
Napan
Jordan Mountain Fault
Gordon
Fault
Downing Head
Lower Cove (and Boss Point)
Joggins
Jordan
Sussex
SUBBASIN
Harvey–Hopewell
CUMBERLAND SUBBASIN
Chignecto Bay
CALEDONIA UPLIFT
Fault
Peekaboo Corner
Fault
Alma
Bloomfield
Hill
Clover
MONCTON
Bay of Fundy
Nova Scotia
0
10 km
Shepody–Beckwith Fault
Hard Ledges Syncline
Maringouin Anticline
Inset: expanded view of Maringouin Peninsula

Figure 6. Distribution of subbasins and crystalline uplifts in the Maritimes Basin of southeastern New Brunswick. The Hastings Uplift, Westmorland Uplift, and New Brunswick Platform are subsurface basement 'ridges' or blocks overlain by a cover of Late Carboniferous strata. Fault traces on map are projected to surface where they are buried beneath the Mabou unconformity (e.g., Saint-Joseph Fault) or Pictou unconformity (e.g., Dorchester and Port Elgin faults). Map sources are Keppie (1979), Potter et al. (1979), Howie (1986), Martel (1987), St. Peter (1993, 2006a), and Ryan and Boehner (1994).

The basement blocks of particular importance to the present study are the Caledonia Uplift (largely exhumed), Westmorland Uplift (largely buried), and northeast extension of the Mascarene Uplift (largely buried beneath the New Brunswick Platform). These uplifts (Fig. 6, 7) became essentially passive highs during the Late Carboniferous. From the Late Devonian through the Early Carboniferous, however, they were the main suppliers of sediment to the adjoining subbasins and were the provenance of Late Devonian–Early Carboniferous strata. Given the provenance role of these basement blocks, a few words are warranted about their lithological variability.

Caledonia Uplift

The Caledonia Uplift is part of the Avalonia tectonostratigraphic division (Fig. 5). Various authors have summarized the geology and plate tectonic evolution of Avalonia in New Brunswick (Ruitenberg et al. 1979; Nance 1987; Bevier and Barr 1990; Bevier et al. 1990; Barr and White 1991, 1996; Fyffe et al. 1991; Barr et al. 2002a, 2003). McLeod et al. (1994) compiled a geology map of the northeastern part of the uplift at a scale of 1:250 000.

The Caledonia Uplift is largely exposed at surface and lies south of the Clover Hill, Gordon Falls, and Caledonia faults (Fig. 6). It comprises the Broad River Group and Coldbrook Group, both of which have associated cogenetic intrusive suites (Barr and White 1999). The Broad River Group underlies the eastern end of the Caledonia Uplift. It comprises ca. 620 Ma tuffaceous, volcanic, and sedimentary rocks as well as coeval dioritic and granitic plutons (Barr and White 1999). The Coldbrook Group occurs mainly in the western part of the uplift and is younger (560–550 Ma) than the Broad River Group. The Coldbrook Group comprises subaerial dacitic to rhyolitic tuffs and flows, basalt, and tuffaceous and clastic sedimentary rocks, all of which were intruded by gabbroic and syenogranitic plutons. Intercalated terrestrial mafic and felsic volcanic rocks and minor sedimentary rocks of the upper Coldbrook Group are exposed along the northern flank of the uplift immediately south of the Caledonia Fault.

About 1.3 km northwest of Shepody Mountain, a northeast-trending wedge of fractured, schistose, mafic volcanic rocks is separated from the main body of the Caledonia Uplift to the northwest. The wedge is in fault contact with the Boss Point Formation (Cumberland Group) on the northwest and with the Hopewell Cape Formation (Mabou Group) and Lime-kiln Brook Formation (Windsor Group) on the southeast (Fig. 8). The mafic rocks are presumably correlative with the Broad River Group, which is widely exposed about 2 km to the northwest.

At Cape Station approximately 4.5 km east-northeast of Shepody Mountain, geophysical data show a positive aeromagnetic anomaly with a peak value that is about 120 gammas above the local regional field (Geological Survey of Canada 1958). The anomaly lies south of the Wood Creek Fault and north of the Shepody–Beckwith Fault (Fig. 8) and is interpreted to result from pre-Late Devonian crystalline basement. No exposures have been found in the overlying low marshy ground between Hamilton Creek and Demoiselle Creek (Plate 4) to confirm this interpretation, but the anomaly's similarity to others of comparable magnitude in the adjacent Caledonia Uplift strongly suggests basement rock either at or very near surface. The apparent presence of basement in the Cape Station area supports the interpreted location of the western termination of the Hastings Uplift (Fig. 8), which is a refinement of previous delineations of that uplift by Martel (1987) and St. Peter (1993).

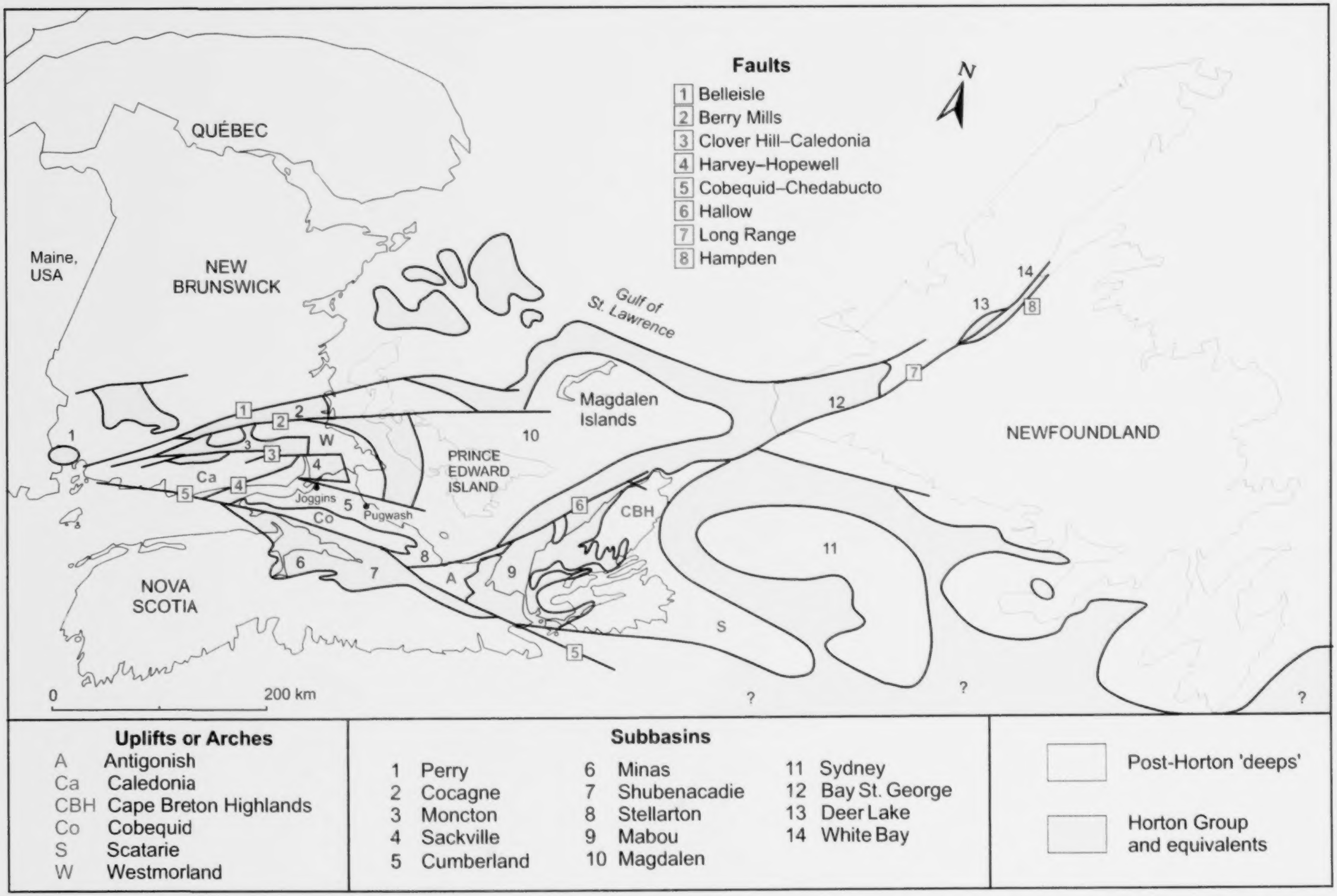

Faults
1 Belleisle
2 Berry Mills
3 Clover Hill–Caledonia
4 Harvey–Hopewell
5 Cobequid–Chedabucto
6 Hallow
7 Long Range
8 Hampden
N
QUÉBEC
Maine, USA
NEW BRUNSWICK
Gulf of St. Lawrence
Magdalen Islands
NEWFOUNDLAND
PRINCE EDWARD ISLAND
NOVA SCOTIA
CBH
Ca
Co
W
A
S
Joggins
Pugwash
1
2
3
4
5
6
7
8
9
10
11
12
13
14
?
?
?
0
200 km
Uplifts or Arches
A Antigonish
Ca Caledonia
CBH Cape Breton Highlands
Co Cobequid
S Scatarie
W Westmorland
Subbasins
1 Perry
2 Cocagne
3 Moncton
4 Sackville
5 Cumberland
6 Minas
7 Shubenacadie
8 Stellarton
9 Mabou
10 Magdalen
11 Sydney
12 Bay St. George
13 Deer Lake
14 White Bay
Post-Horton 'deeps'
Horton Group and equivalents

Figure 7. Subbasins and uplifts in the Maritimes Basin of Atlantic Canada (from St. Peter 1991). Figure shows distribution of Horton Group and post-Horton 'deeps' where Horton rocks are overlain by thick late Paleozoic sections. (Compiled from Howie and Barss 1974; Wade et al. 1977; Fralick and Schenk 1981; Bradley 1982; Hyde 1982; Keppie 1982; Knight 1983; van de Poll 1983; Martel 1987; Gates 1989; Ryan and Boehner 1990; Ryan et al. 1990a–1990c; Durling and Marillier 1990; McCutcheon 1990; St. Peter and Fyffe 1990; St. Peter 2006a, 2006b.)

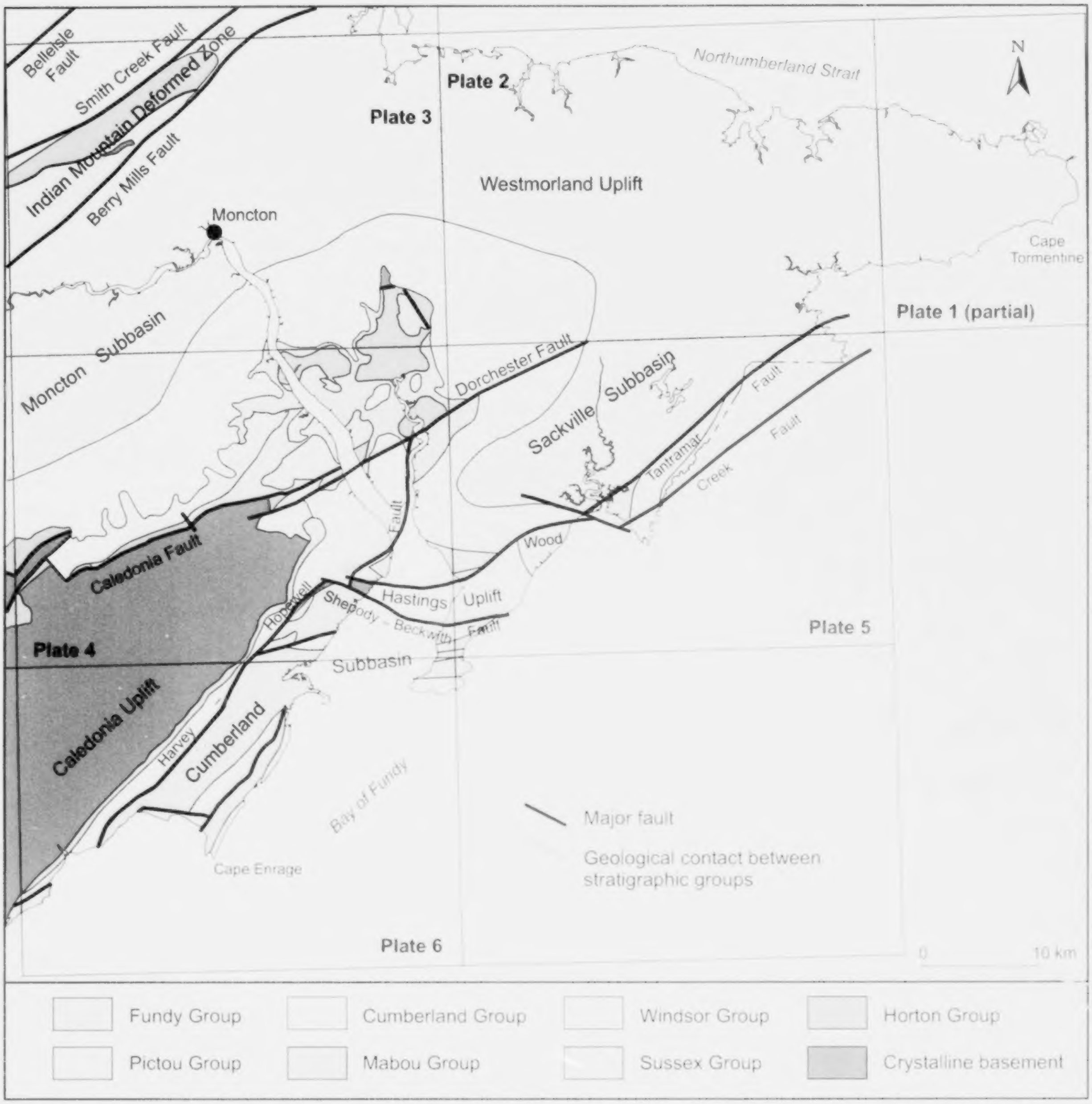
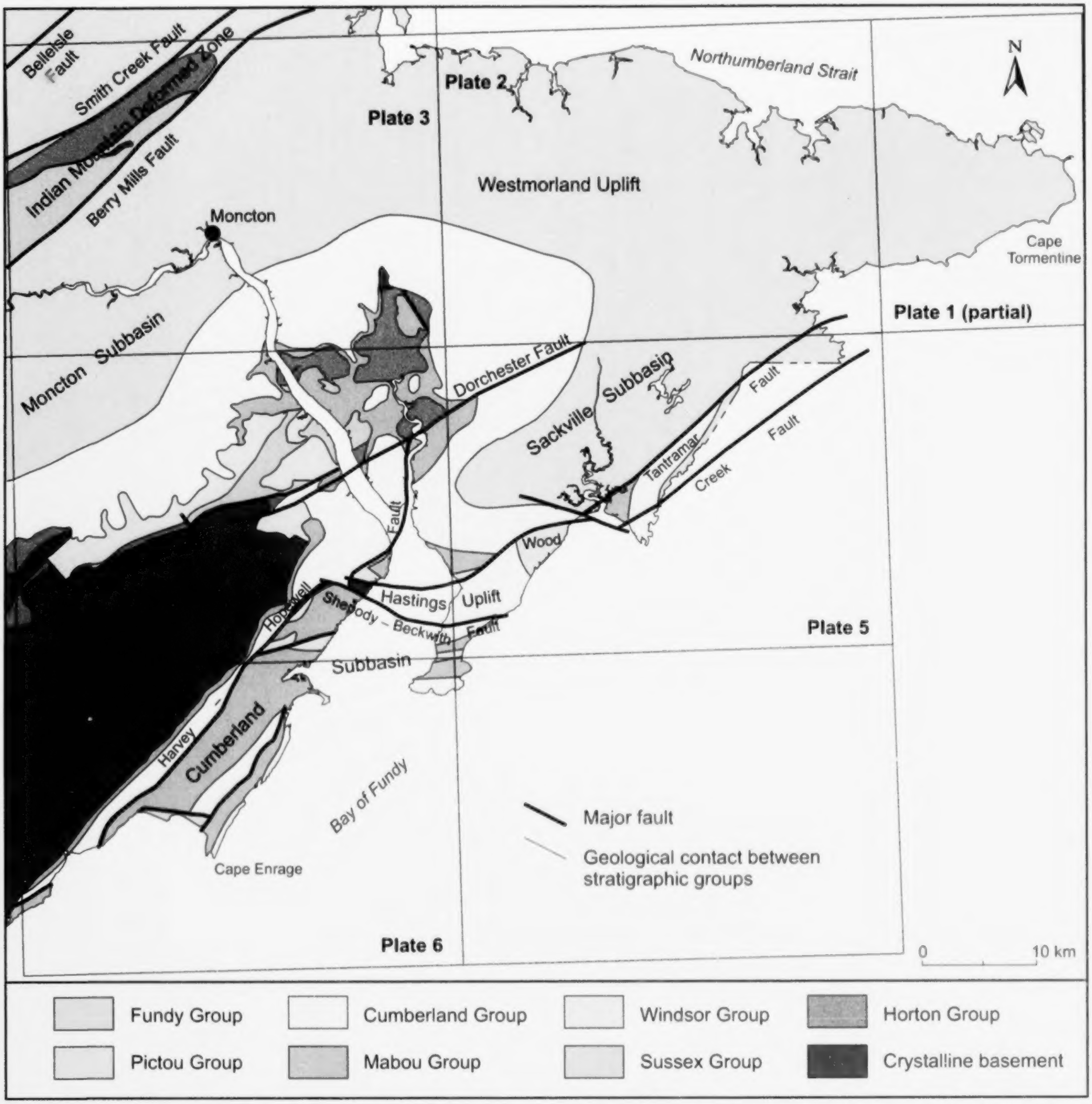

Belleisle Fault
Smith Creek Fault
Indian Mountain Deformed Zone
Berry Mills Fault
Moncton
Plate 2
Plate 3
Northumberland Strait
N
Westmorland Uplift
Cape Tormentine
Plate 1 (partial)
Moncton Subbasin
Dorchester Fault
Sackville Subbasin
Fault
Tantramar
Creek
Fault
Fault
Wood
Caledonia Fault
Hastings Uplift
Hopewell
Shepody - Beckwith Fault
Plate 5
Plate 4
Subbasin
Caledonia Uplift
Harvey
Cumberland
Bay of Fundy
Major fault
Geological contact between stratigraphic groups
Cape Enrage
Plate 6
0
10 km
Fundy Group
Cumberland Group
Windsor Group
Horton Group
Pictou Group
Mabou Group
Sussex Group
Crystalline basement

Figure 8. Simplified geology map of the report area, showing stratigraphy at the group level. See Figure 2 for location of the report area in southeastern New Brunswick.

Westmorland Uplift and Adjacent Inliers

The Brookville terrane of the Ganderia tectonostratigraphic division (van Staal et al. 1996; White and Barr 1996; Samson et al. 2000; Barr et al. 2002a, 2003; Hibbard et al. 2006) lies north of the Clover Hill, Gordon Falls, and Caledonia faults and south of the Kennebecasis Fault (Fig. 5, 6). It underlies the Moncton Subbasin and includes 1) crystalline rocks that form the shallowly buried Westmorland Uplift, and 2) basement rocks underlying the Carboniferous cover rocks in the Indian Mountain Deformed Zone (IMDZ) south of the Smith Creek and


Belleisle Fault
Smith Creek Fault
Indian Mountain Deformed Zone
Berry Mills Fault
Moncton
Plate 3
Plate 2
Northumberland Strait
N
Westmorland Uplift
Cape Tormentine
Plate 1 (partial)
Moncton Subbasin
Dorchester Fault
Sackville Subbasin
Fault
Fault
Tantramar
Creek
Fault
Wood
Hastings
Uplift
Hopewell
Shepody – Beckwith Fault
Subbasin
Plate 5
Harvey
Cumberland
Bay of Fundy
Cape Enrage
Major fault
Geological contact between stratigraphic groups
Plate 6
0
10 km
Fundy Group
Cumberland Group
Windsor Group
Horton Group
Pictou Group
Mabou Group
Sussex Group
Crystalline basement

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North River faults. The Brookville terrane is considered part of the peri-Gondwanan Realm that remained separate from Avalonia until at least the Cambro–Ordovician (Potter et al. 2008). The terrane includes Neoproterozoic platformal marbles, quartzites, phyllites, and conglomerates of the Green Head Group and younger paragneisses (641 Ma) and orthogneiss (605 Ma) of the Brookville Gneiss. The Green Head sedimentary rocks and Brookville Gneiss are intruded by late Neoproterozoic–Cambrian bodies of gabbro, quartz diorite, granodiorite, monzogranite, and syenogranite as well as Devonian intrusive bodies including granite and gabbro (Barr et al. 2002b; Cook et al. 2007).

An inlier of Middle Devonian megacrystic granite (exhumed Westmorland Uplift) is exposed along tributaries draining into Memramcook River between Calhoun and Gaytons (Plate 3). Large quarries in this granite are the sole source of quality aggregate southeast of Moncton in New Brunswick. The fault contact between the granite and the Memramcook Formation is exposed along the south wall of the Gaytons quarry (Modern Construction (1987) Ltd.) on the east side of Memramcook River (St. Peter 1992). Just southeast of the inlier is an isolated exposure of basement granite on the east bank of Prairie Brook, about 400 m from its confluence with Stony Creek (Plate 3). The contact between the granite and nearby redbeds of the Memramcook Formation is unexposed, but a 3 m wide, easterly striking breccia zone in the granite suggests a fault contact with the Memramcook. Steep bedding dips in adjacent Memramcook exposures also imply the possibility of a tectonic contact with the granite.

The granites in the Calhoun–Gaytons and Prairie Brook areas provide surface evidence of the otherwise buried Westmorland Uplift (Fig. 6–8). In addition, data from 12 boreholes (Table 1) show that the uplift is shallowly buried in the region around Moncton and east of there for approximately 40 km. A gradual increase in the burial depth toward the east is revealed by core from Well 402 just north of Port Elgin, which indicates granite at 921 m below surface. ***(See Appendix 1 for details about this and all other numbered wells cited in Chapter 1.)*** Southwest of Moncton, the contact between the Westmorland Uplift and Carboniferous cover rocks plunges significantly, appearing (for example) at 1406 m below surface in Well 146 just west of Colpitts Settlement (Plate 4).

Green and pink, chloritic, mylonitic, cataclastic granitoid rocks and associated minor pink, fine-grained, less deformed granites are exposed in small inliers about 10 km northwest of Moncton near The Gorge (St. Peter 2006a, his Fig. 6). The rocks are exposed as small faulted blocks in both depositional and tectonic contact with redbeds of the Sussex Group (Fig. 8). Quarries in the basement granitoid rocks and adjacent Sussex conglomerates provide a valuable source of aggregate for Moncton and the surrounding area.

Kingston Uplift

The Kingston Uplift lies west of the report area between the Kennebecasis Fault and Belleisle Fault (Fig. 6) and is believed to continue along strike to the northeast, forming the floor of the Cocagne Subbasin. The uplift comprises mainly Silurian volcanic, volcaniclastic, sedimentary, and granitoid rocks (Barr et al. 2002a, 2003) and is interpreted as a volcanic arc lying on the Neoproterozoic–Cambrian basement of Ganderia, which is exposed immediately north of the Belleisle Fault (Johnson 2001, 2003a).

Table 1. Boreholes that intersected crystalline basement rocks of the Westmorland Uplift. Appendix 1 provides additional data for each well under its Unique Identification (UI) number.

UI Number	Plate No.	Basement Depth Below Surface (m)	Basement Rock
146	Plate 4	1406	Limestone and marble
398	Plate 2	295	Granite
399	Plate 2	392	Granite
401	Plate 2	149	Granite
402	Plate 2	921	Granite
406	Plate 3	128	Granite
407	Plate 3	108	Granite
420	Plate 3	120	Gabbro
421	Plate 3	120	Gabbro
422	Plate 3	124	Gabbro
423	Plate 3	118	Gabbro
682	Plate 3	140	Gabbro

The basement rocks exhumed and buried beneath the Maritimes Basin of southeastern New Brunswick are characterized by numerous northeast-trending faults (Fig. 6, 8; Leger 1986; Leger and Williams 1986). Ductile dextral movements on those faults have been assigned a Precambrian age by Nance (1987) and an Acadian (Devonian) age by Leger and Williams (1986) and Leger et al. (1988). Whatever the timing of early ductile displacements, Late Devonian–Carboniferous brittle extensional and compressional displacements on the faults controlled the inception and inversion of the successions within the component subbasins of the Maritimes Basin (St. Peter 1993).

The Late Devonian–Carboniferous strata of the Maritimes Basin are the first overlap assemblage linking Meguma and Avalonia, which implies that Meguma docked with North America in the late Paleozoic (Williams and Hatcher 1982). The suture zone between the two tectonostratigraphic divisions is the Cobequid–Chedabucto Fault (Fig. 5), a steeply dipping, dextral, transcurrent structure in Nova Scotia (Eisbacher 1969; Keppie 1982). The fault is linked with an imbricate thrust front along the north side of Bay of Fundy in New Brunswick (Ruitenberg and McCutcheon 1982; Mosher and Rast 1984; Rast 1984; Nance and Warner 1986). Movement on the Cobequid–Chedabucto Fault during the Late Carboniferous (Alleghenian Orogeny) is reflected by transpressive displacements on faults cutting Carboniferous sequences of southeastern New Brunswick.

Maritimes Basin

Introduction

The Maritimes Basin was named by Roliff (1962) for the mainly continental clastic cover sequence of late Paleozoic postorogenic (post-Acadian) rocks that straddle the crystalline basement tectonostratigraphic divisions of the northeastern Appalachians (Fig. 4, 5). The basin is the largest intermontane depocentre in the Appalachian Mountain system (Williams 1974). It has an area of 148 000 km^2, about 70% of which lies offshore in the Gulf of St.

Lawrence and beneath the continental shelf. Thickness estimates indicate that up to 12 km of predominantly continental clastic sediments presently exists in the deepest part of the basin in the Magdalen Islands area (Fig. 7; Howie 1988; Bell and Howie 1990).

The Maritimes Basin is a composite structure comprising a series of smaller depocentres or subbasins separated by intervening horsts or uplifts (Howie and Barss 1974; Wade et al. 1977; Fralick and Schenk 1981; Bradley 1982; Hyde 1982; Keppie 1982; Knight 1983; van de Poll 1983, 1995; Gibling and Rust 1986; Boehner et al. 1986; Yeo and Ruixing (*sic*) 1986; Martel 1987; McCutcheon and Robinson 1987; Gates 1989; Hamblin 1989, 1992; Durling and Marillier 1990; McCutcheon 1990; St. Peter and Fyffe 1990; St. Peter 1993; Lynch and Tremblay 1994; Nickerson 1994; Ryan and Boehner 1994; Gibling 1995). The major depocentres in the report area comprise the Cocagne, Moncton, Sackville, and Cumberland subbasins. The horsts consist of the New Brunswick Platform, Westmorland Uplift, Caledonia Uplift, and Hastings Uplift (Fig. 6, 8). Additional subbasins and uplifts are located in the Maritimes Basin beyond New Brunswick (Fig. 7).

The shapes of the subbasins range from linear grabens (Moncton and Deer Lake subbasins in New Brunswick and Newfoundland, respectively: Hyde 1979; St. Peter 1993; Hyde et al. 1994) to half-grabens (Ainslie and Cabot subbasins on Cape Breton Island: Hamblin 1992), to rhomboidal (Stellarton Basin in northern mainland Nova Scotia: Yeo 1985; and Sackville Subbasin in New Brunswick: Martel 1987). Depositional margins are preserved in part within all of these subbasins. Initiation, subsidence, and inversion of individual subbasins took place over periods of 10 Ma to 20 Ma, whereas the Maritimes Basin as a whole received sediment for about 90 Ma (St. Peter 1993, his Fig. 8).

The locations of active depocentres in the Maritimes Basin changed through time. For example, the Moncton Subbasin was an actively subsiding depocentre during the Late Devonian to Early Carboniferous (Tournaisian), whereas the Cumberland Subbasin was a major deposition site in the Late Carboniferous (Westphalian) (Ryan et al. 1991; St. Peter 1993). Spatial and temporal data on the subbasins indicate that, immediately following Acadian orogenesis, many intraterrane and interterrane faults were active in the juvenile mountains and led to widely distributed depocentres. The data also show that, as the orogen matured throughout the Carboniferous, many of the less significant intraterrane faults became inactive, leaving displacements and associated subsidence geographically restricted to the major terrane-boundary fault systems.

The boundaries as currently defined between the uplifts and subbasins of the Maritimes Basin in southeastern New Brunswick are delineated mainly but not solely by major and minor faults. Chapter 3 on ***Structural Geology*** describes these faults and other deformation features in the report area and offers a further discussion of subbasin boundaries. Figure 84, which shows the uplifts, subbasins, and boundary-defining faults, is placed for convenience within that chapter. The reader may wish to preview Figure 84 for a more detailed depiction of the subbasin boundaries than is provided here (Chapter 1) in Figures 6 and 8.

Stratigraphic Overview

The stratigraphy of the Maritimes Basin has been summarized by Roliff (1962), Kelley (1967), Hacquebard (1972), Howie and Barss (1974, 1975), Williams (1974), van de Poll (1978, 1995), and Gibling (1995). Historically and in a regional sense, the stratigraphic succession has been divided into five lithostratigraphic groups. In ascending order they are the Horton, Windsor, Mabou, Cumberland, and Pictou groups (Hacquebard 1972; Howie and Barss 1974, 1975; Williams 1974; Ryan et al. 1991). Recent work in southern New Brunswick (St. Peter 2002; Park and St. Peter 2005; St. Peter 2006a) demonstrates that an unconformity exists in the succession previously mapped as the Horton Group, and consequently the Horton has been divided into two groups. The name 'Horton Group' is retained for strata below the unconformity, and a new name, 'Sussex Group,' is applied to beds above the unconformity. Figure 8 outlines the six stratigraphic groups, and Figure 9 displays the stratigraphic successions within those groups as preserved in the subbasins and on the adjacent uplifts of southeastern New Brunswick. These stratigraphic successions are as follows.

The earliest fill in the Maritimes Basin is the *Horton Group*, a succession up to 5 km thick of alluvial and lacustrine strata and local volcanic rocks of Late Devonian–Early Carboniferous (early to middle Tournaisian) age (Hacquebard 1972). The Horton Group in southeastern New Brunswick comprises the Memramcook, McQuade Brook, Albert, Steeves Mills, and Indian Mountain formations.

In southern New Brunswick, the Horton Group is unconformably overlain by the Early Carboniferous (latest middle to late Tournasian) *Sussex Group*. In the southeastern Moncton Subbasin, the Sussex Group comprises proximal rocks of the Round Hill Formation and distal equivalent mudrocks and evaporites of the Gautreau Formation. The coarser Round Hill rocks and the finer Gautreau rocks are gradationally succeeded by a varied thickness of fine-grained redbeds of the Weldon Formation. In the Hillsborough area, the Weldon contains a thin layer of volcanic ash named the Boyd Creek Tuff. North of Moncton is the Indian Mountain Deformed Zone (IMDZ), a block that represents the complex boundary zone between the Cocagne Subbasin and Westmorland Uplift (Fig. 10). In the IMDZ, the Sussex Group comprises two coarse clastic units: the basal Stilesville Formation and the uppermost Briggs Cross Formation. Between these two coarse units are two fine-grained units, those being the Gautreau and Weldon formations.

The Horton and Sussex groups are succeeded by the Early Carboniferous (early to middle Visean) *Windsor Group*, a terrestrial and marine sequence of strata that unconformably overlie the Horton and Sussex groups and also overlap pre-Late Devonian rocks (Kelley 1967). The Windsor Group was divided by Bell (1929) into five subzones (A to E) that are interpreted as transgressive and regressive cycles (Schenk 1969). The cycles comprise algal and brachiopod-bearing patch reefs, algal-laminated carbonates, gypsum, anhydrite, salt, local potash beds, red mudstones, and coarse-grained clastic rocks. The clastic rocks are situated on the upland side of and adjacent to transgressive margins of the Windsor Sea (Gussow 1953; Schenk 1969; Smith and Collins 1984). In the Moncton Subbasin and on the Caledonia Uplift, basal carbonates of the Windsor Group are underlain by coarse terrestrial clastics of the Hillsborough Formation (Wright 1922; Gussow 1953; St. Peter 1992, 1993).

The Windsor Group is overlain by the Early Carboniferous (middle Visean to early Namurian) *Mabou Group* (Boehner 1985; Utting 1987; Ryan and Boehner 1994). In New Brunswick the redbeds that overlie the Windsor strata were historically called the 'Hopewell Group' (Norman

1941a; Flaherty and Norman 1941; Gussow 1953). However, to encourage a regionally simplified stratigraphic nomenclature, Belt (1964, 1965) recommended replacing the name 'Hopewell Group' with 'Mabou Group' to describe the terrestrial mudstones and sandstones of the Maringouin and Shepody formations in southeastern New Brunswick. The current report follows Belt's recommendation, instating 'Mabou Group' herein for the dominantly redbed sequence overlying the Windsor Group in southeastern New Brunswick. The Enragé and Hopewell Cape formations are also assigned to the Mabou Group, together with the Maringouin and Shepody formations.

The Mabou Group is succeeded regionally in the Maritimes Basin by the Late Carboniferous *Cumberland Group*. Under its revised definition, the Cumberland includes all strata previously assigned to the Riversdale and Cumberland groups (Ryan et al. 1991; Ryan and Boehner 1994). Cumberland rocks consist of terrestrial to possibly partly estuarine (Calder et al. 1997) coarse conglomerates and sandstones with lesser mudstones and many coal seams, the most famous of which (Hacquebard 1972) occur at Joggins (Fig. 6) in Nova Scotia. The Cumberland strata range from late Namurian C (late Yeadonian) to Westphalian A (Langsettian) and possibly early Westphalian B (early Duckmantian). In southeastern New Brunswick they comprise the Boss Point and Grande Anse formations.

The *Pictou Group* is the youngest sequence of late Paleozoic rocks in New Brunswick, ranging from late Westphalian B (late Duckmantian) to Early Permian (Artinskian) (Barss and Hacquebard 1967; Hacquebard 1972; van de Poll 1989). The group reaches up to 3 km thick in the Gulf of St Lawrence area (Ryan et al. 1991; Giles and Utting 1999a). Pictou strata comprise fining-upward fluvial cycles of grey and red sandstones and mudstones with minor, very thin coal seams. In southeastern New Brunswick the Late Carboniferous Pictou Group comprises, in ascending order, the Salisbury, Richibucto, and Tormentine formations. The Salisbury Formation is replaced by the Minto Formation on the New Brunswick Platform (Fig. 6).

The stratigraphic succession in the Maritimes Basin is punctuated by disconformities, paraconformities, and angular unconformities that for the most part define boundaries between groups (Bell 1927, 1940; Kelley 1967; Smith and Collins 1984; St. Peter 1993). As described in Chapter 3, the degree of angular discordance and the duration of time breaks represented by the unconformities vary within individual subbasins and from one subbasin to another. Two regional disconformities or unconformities apparently affected the entire Maritimes Basin. One is at the base of the Windsor Group (Bell 1914, 1927; Gussow 1953; Smith and Collins 1984; St. Peter 1993), and the other is at the base of the Cumberland Group (Bell 1944, p. 24). These two major unconformities (Fig. 9) reflect periods of deformation that resulted in inversion and partial erosion of the succession prior to subsidence and initiation of the succeeding depositional sequence (St. Peter 1993). The degree of deformation at the basal boundary of the Cumberland Group varies from angular discordance at subbasin margins to stratal concordancy in the axial part of the Sackville and Cumberland subbasins.

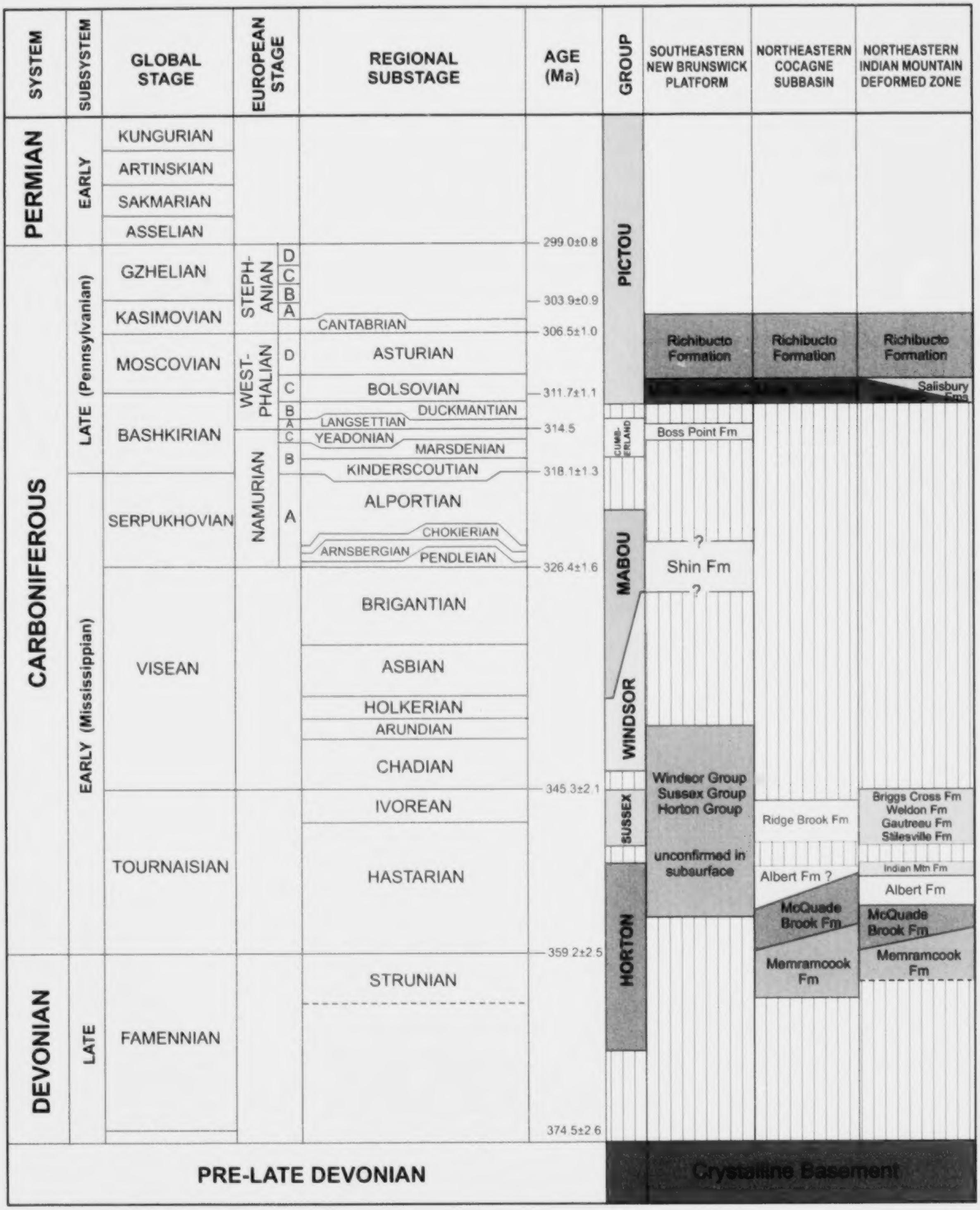
SYSTEM
SUBSYSTEM
GLOBAL STAGE
EUROPEAN STAGE
REGIONAL SUBSTAGE
AGE (Ma)
GROUP
SOUTHEASTERN NEW BRUNSWICK PLATFORM
NORTHEASTERN COCAGNE SUBBASIN
NORTHEASTERN INDIAN MOUNTAIN DEFORMED ZONE
PERMIAN
EARLY
KUNGURIAN
ARTINSKIAN
SAKMARIAN
ASSELIAN
CARBONIFEROUS
LATE (Pennsylvanian)
EARLY (Mississippian)
GZHELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
STEPH-ANIAN
WEST-PHALIAN
NAMURIAN
D
C
B
A
CANTABRIAN
ASTURIAN
BOLSOVIAN
DUCKMANTIAN
LANGSETTIAN
YEADONIAN
MARSDENIAN
KINDERSCOUTIAN
ALPORTIAN
CHOKIERIAN
ARNSBERGIAN
PENDLEIAN
BRIGANTIAN
ASBIAN
HOLKERIAN
ARUNDIAN
CHADIAN
IVOREAN
HASTARIAN
STRUNIAN
DEVONIAN
LATE
FAMENNIAN
299.0±0.8
303.9±0.9
306.5±1.0
311.7±1.1
314.5
318.1±1.3
326.4±1.6
345.3±2.1
359.2±2.5
374.5±2.6
PICTOU
CUMB-ERLAND
MABOU
WINDSOR
SUSSEX
HORTON
Richibucto Formation
Richibucto Formation
Richibucto Formation
Salisbury Fms
Boss Point Fm
?
Shin Fm
?
Windsor Group
Sussex Group
Horton Group
unconfirmed in subsurface
Ridge Brook Fm
Albert Fm ?
McQuade Brook Fm
Memramcook Fm
Briggs Cross Fm
Weldon Fm
Gautreau Fm
Stilesville Fm
Indian Mtn Fm
Albert Fm
McQuade Brook Fm
Memramcook Fm
PRE-LATE DEVONIAN
Crystalline Basement

Figure 9. Table of formations for subbasins and uplifts in the Maritimes Basin of southeastern New Brunswick and adjacent Nova Scotia. Carboniferous global and regional stages and substages are adapted from Wagner and Winkler Prins (1997) and Heckel and Clayton (2006). Early–Late Carboniferous boundary position is from Lane et al. (1999) and Heckel and Clayton (2006). Radiometric ages in Ma are from Okulitch (1995). *(Caption continues on facing page.)*

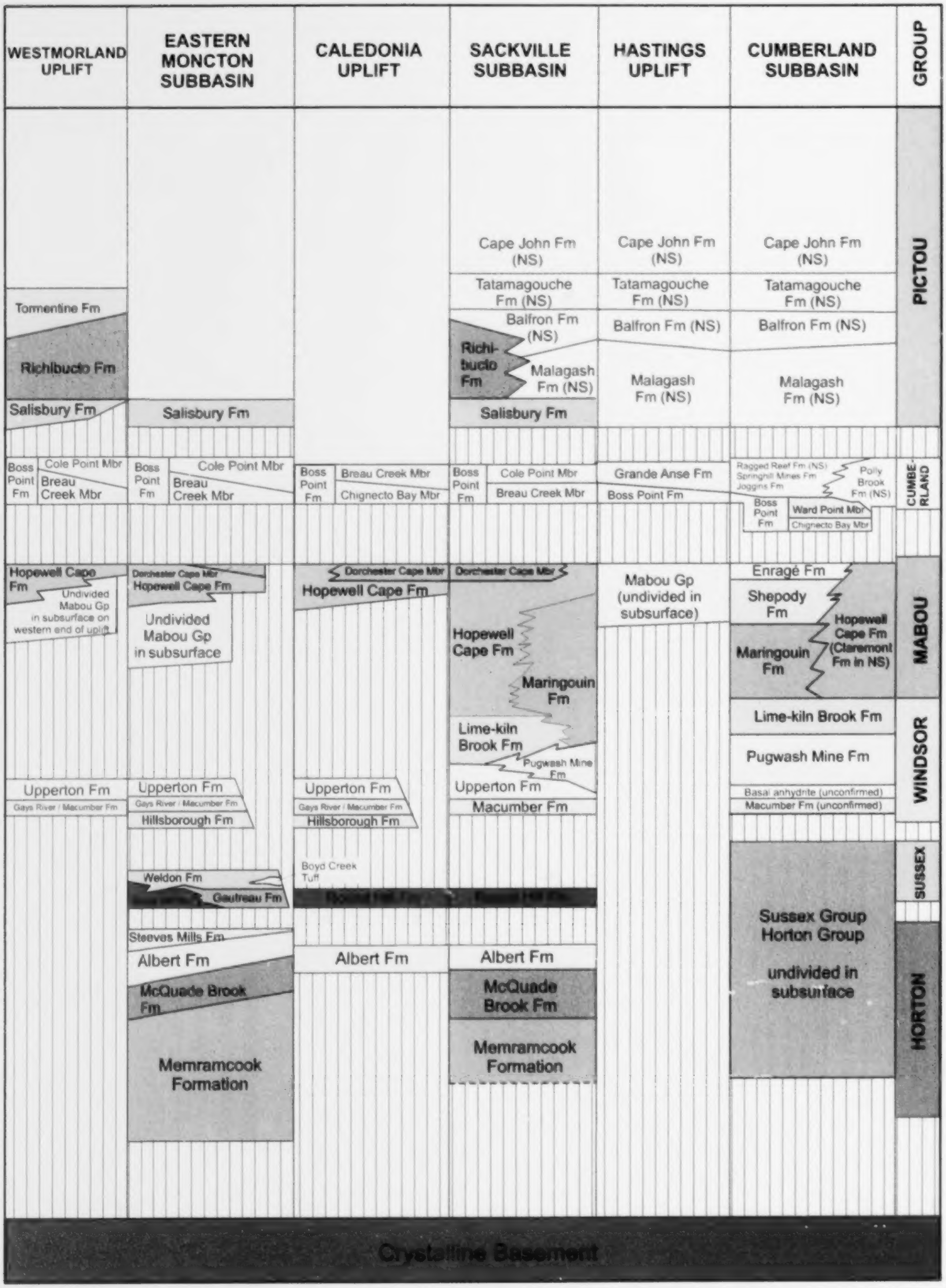

Figure 9 *(cont'd)*. Vertical ruled lines represent angular unconformities, disconformities, or paraconformities. Question mark (?) indicates that the unit may exist in subsurface. NS indicates that the unit exists in Nova Scotia. Nova Scotian formations and age ranges are from Ryan and Boehner (1994). Base of the Cumberland Group is late Yeadonian but because of space considerations is shown beyond its actual range in the Cumberland Subbasin.

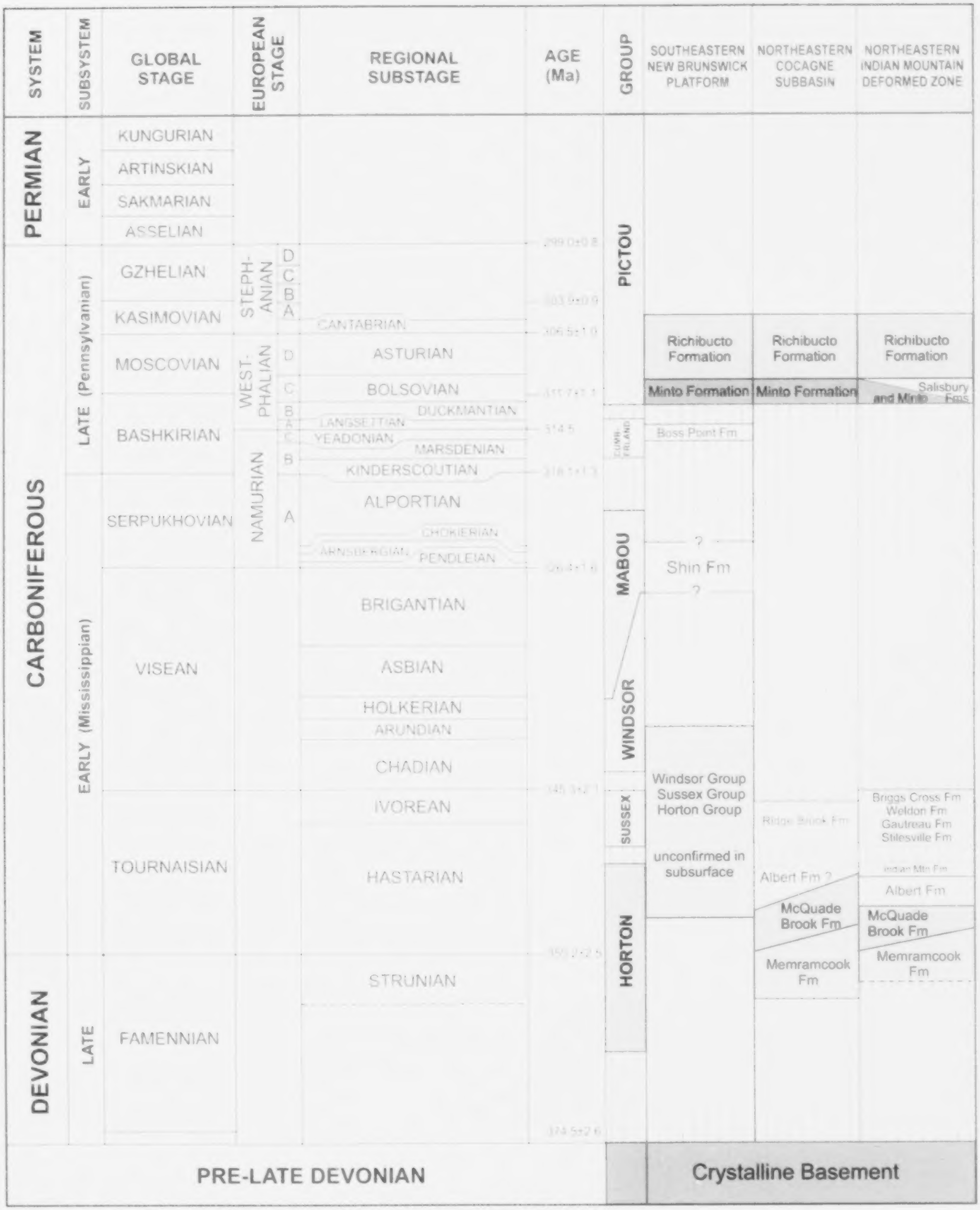
SYSTEM
SUBSYSTEM
GLOBAL STAGE
EUROPEAN STAGE
REGIONAL SUBSTAGE
AGE (Ma)
GROUP
SOUTHEASTERN NEW BRUNSWICK PLATFORM
NORTHEASTERN COCAGNE SUBBASIN
NORTHEASTERN INDIAN MOUNTAIN DEFORMED ZONE
PERMIAN
EARLY
KUNGURIAN
ARTINSKIAN
SAKMARIAN
ASSELIAN
CARBONIFEROUS
LATE (Pennsylvanian)
GZHELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
STEPH-ANIAN
D
C
B
A
WEST-PHALIAN
D
C
B
A
CANTABRIAN
ASTURIAN
BOLSOVIAN
DUCKMANTIAN
LANGSETTIAN
YEADONIAN
MARSDENIAN
KINDERSCOUTIAN
NAMURIAN
C
B
A
EARLY (Mississippian)
SERPUKHOVIAN
ALPORTIAN
CHOKIERIAN
ARNSBERGIAN
PENDLEIAN
VISEAN
BRIGANTIAN
ASBIAN
HOLKERIAN
ARUNDIAN
CHADIAN
TOURNAISIAN
IVOREAN
HASTARIAN
DEVONIAN
LATE
FAMENNIAN
STRUNIAN
299.0±0.8
303.9±0.9
306.5±1.0
311.7±1.1
314.5
318.1±1.3
326.4±1.6
345.3±2.1
359.2±2.5
374.5±2.6
PICTOU
CUMB-ERLAND
MABOU
WINDSOR
SUSSEX
HORTON
Richibucto Formation
Richibucto Formation
Richibucto Formation
Minto Formation
Minto Formation
Salisbury and Minto Fms
Boss Point Fm
?
Shin Fm
?
Windsor Group
Sussex Group
Horton Group
unconfirmed in subsurface
Ridge Brook Fm
Albert Fm ?
McQuade Brook Fm
Memramcook Fm
Briggs Cross Fm
Weldon Fm
Gautreau Fm
Stilesville Fm
Indian Mtn Fm
Albert Fm
McQuade Brook Fm
Memramcook Fm
PRE-LATE DEVONIAN
Crystalline Basement

Figure 9. Table of formations for subbasins and uplifts in the Maritimes Basin of southeastern New Brunswick and adjacent Nova Scotia. Carboniferous global and regional stages and substages are adapted from Wagner and Winkler Prins (1997) and Heckel and Clayton (2006). Early–Late Carboniferous boundary position is from Lane et al. (1999) and Heckel and Clayton (2006). Radiometric ages in Ma are from Okulitch (1995). *(Caption continues on facing page.)*

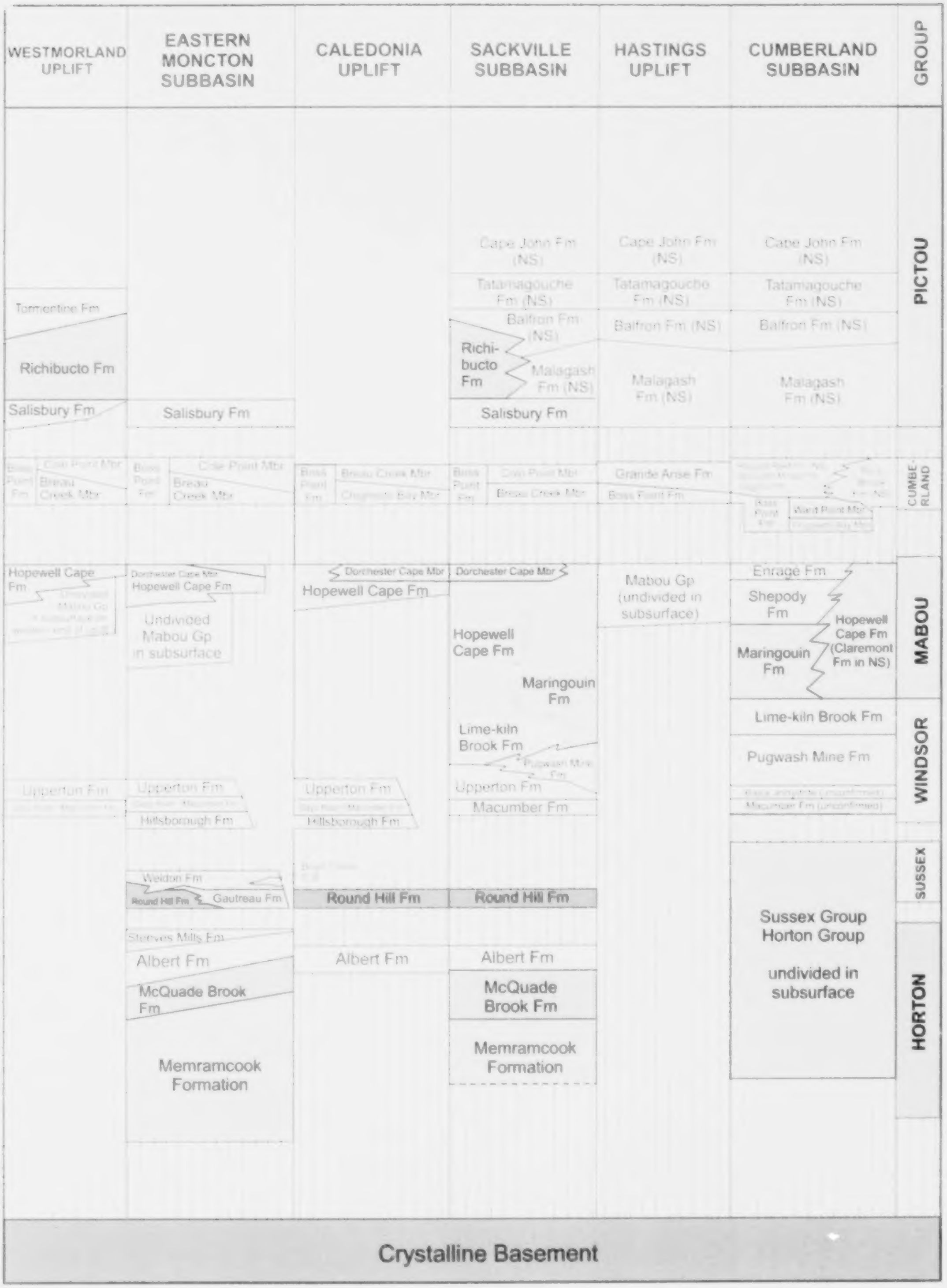
WESTMORLAND UPLIFT
EASTERN MONCTON SUBBASIN
CALEDONIA UPLIFT
SACKVILLE SUBBASIN
HASTINGS UPLIFT
CUMBERLAND SUBBASIN
GROUP
PICTOU
CUMBE-RLAND
MABOU
WINDSOR
SUSSEX
HORTON
Cape John Fm (NS)
Tatamagouche Fm (NS)
Balfron Fm (NS)
Malagash Fm (NS)
Tormentine Fm
Richibucto Fm
Richi-bucto Fm
Salisbury Fm
Boss Point Fm
Cole Point Mbr
Breau Creek Mbr
Chignecto Bay Mbr
Grande Anse Fm
Ward Point Mbr
Hopewell Cape Fm
Dorchester Cape Mbr
Undivided Mabou Gp in subsurface
Mabou Gp (undivided in subsurface)
Enrage Fm
Shepody Fm
Maringouin Fm
Hopewell Cape Fm (Claremont Fm in NS)
Lime-kiln Brook Fm
Pugwash Mine Fm
Upperton Fm
Macumber Fm
Hillsborough Fm
Weldon Fm
Round Hill Fm
Gautreau Fm
Stevens Mills Fm
Albert Fm
McQuade Brook Fm
Memramcook Formation
Sussex Group Horton Group undivided in subsurface
Crystalline Basement

Figure 9 *(cont'd).* Vertical ruled lines represent angular unconformities, disconformities, or paraconformities. Question mark (?) indicates that the unit may exist in subsurface. NS indicates that the unit exists in Nova Scotia. Nova Scotian formations and age ranges are from Ryan and Boehner (1994). Base of the Cumberland Group is late Yeadonian but because of space considerations is shown beyond its actual range in the Cumberland Subbasin.

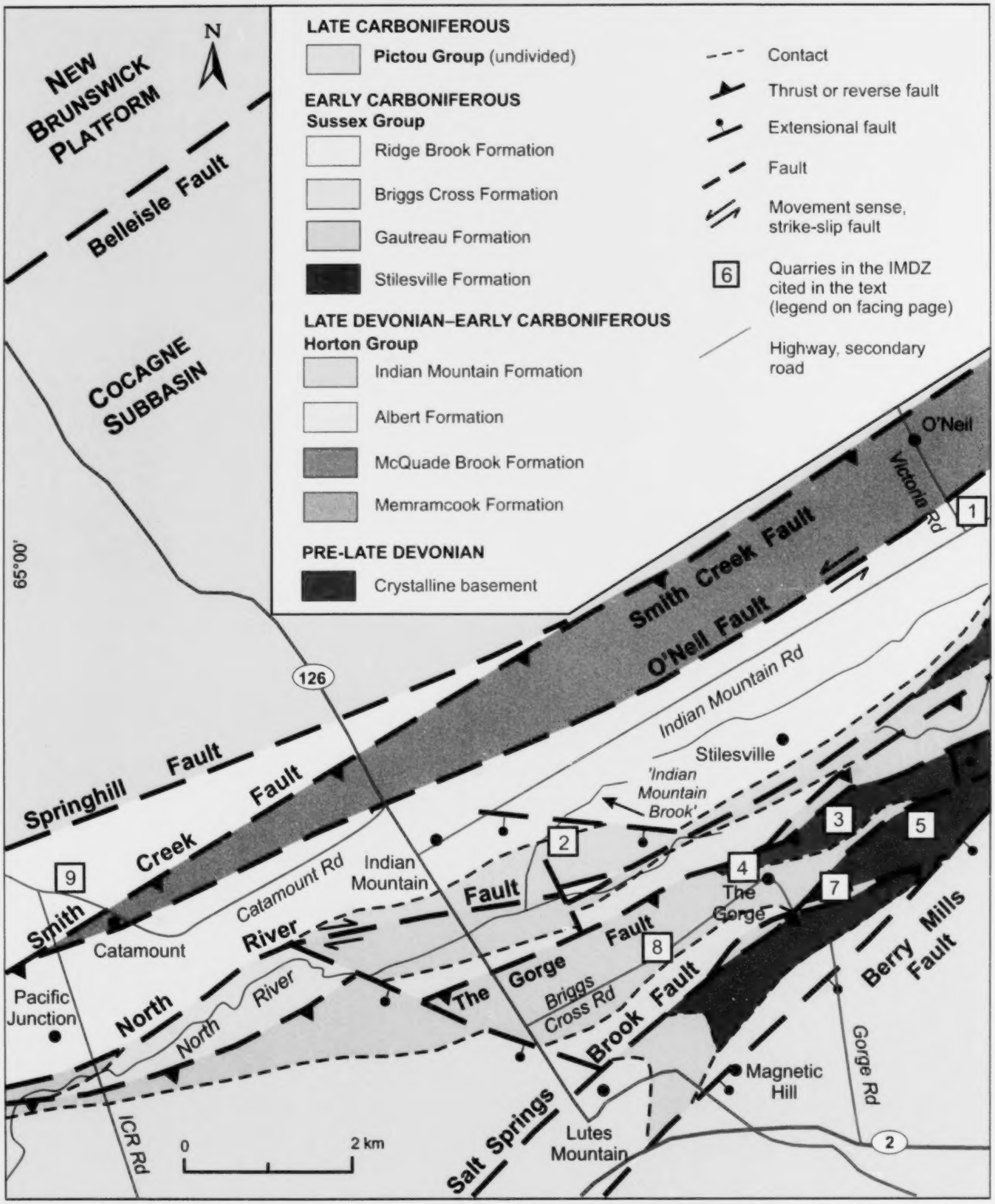
LATE CARBONIFEROUS
Pictou Group (undivided)
EARLY CARBONIFEROUS
Sussex Group
Ridge Brook Formation
Briggs Cross Formation
Gautreau Formation
Stilesville Formation
LATE DEVONIAN–EARLY CARBONIFEROUS
Horton Group
Indian Mountain Formation
Albert Formation
McQuade Brook Formation
Memramcook Formation
PRE-LATE DEVONIAN
Crystalline basement
Contact
Thrust or reverse fault
Extensional fault
Fault
Movement sense, strike-slip fault
6
Quarries in the IMDZ cited in the text (legend on facing page)
Highway, secondary road
N
NEW BRUNSWICK PLATFORM
Belleisle Fault
COCAGNE SUBBASIN
65°00'
Springhill Fault
Smith Creek Fault
O'Neil Fault
O'Neil
Victoria Rd
Indian Mountain Rd
Stilesville
'Indian Mountain Brook'
126
Indian Mountain
Catamount Rd
Catamount
Pacific Junction
North River Fault
North River
The Gorge Fault
Briggs Cross Rd
The Gorge
Brook Fault
Salt Springs
Berry Mills Fault
Magnetic Hill
Lutes Mountain
Gorge Rd
ICR Rd
2
0
2 km
1
2
3
4
5
7
8
9

Figure 10. Geology map of the northeastern Indian Mountain Deformed Zone (IMDZ) showing exhumed panels of the Cocagne Subbasin and Westmorland Uplift. Modified after St. Peter (2006a, his Fig. 6) and Park and St. Peter (2009, their Fig. 2). *(Caption continues on facing page.)*

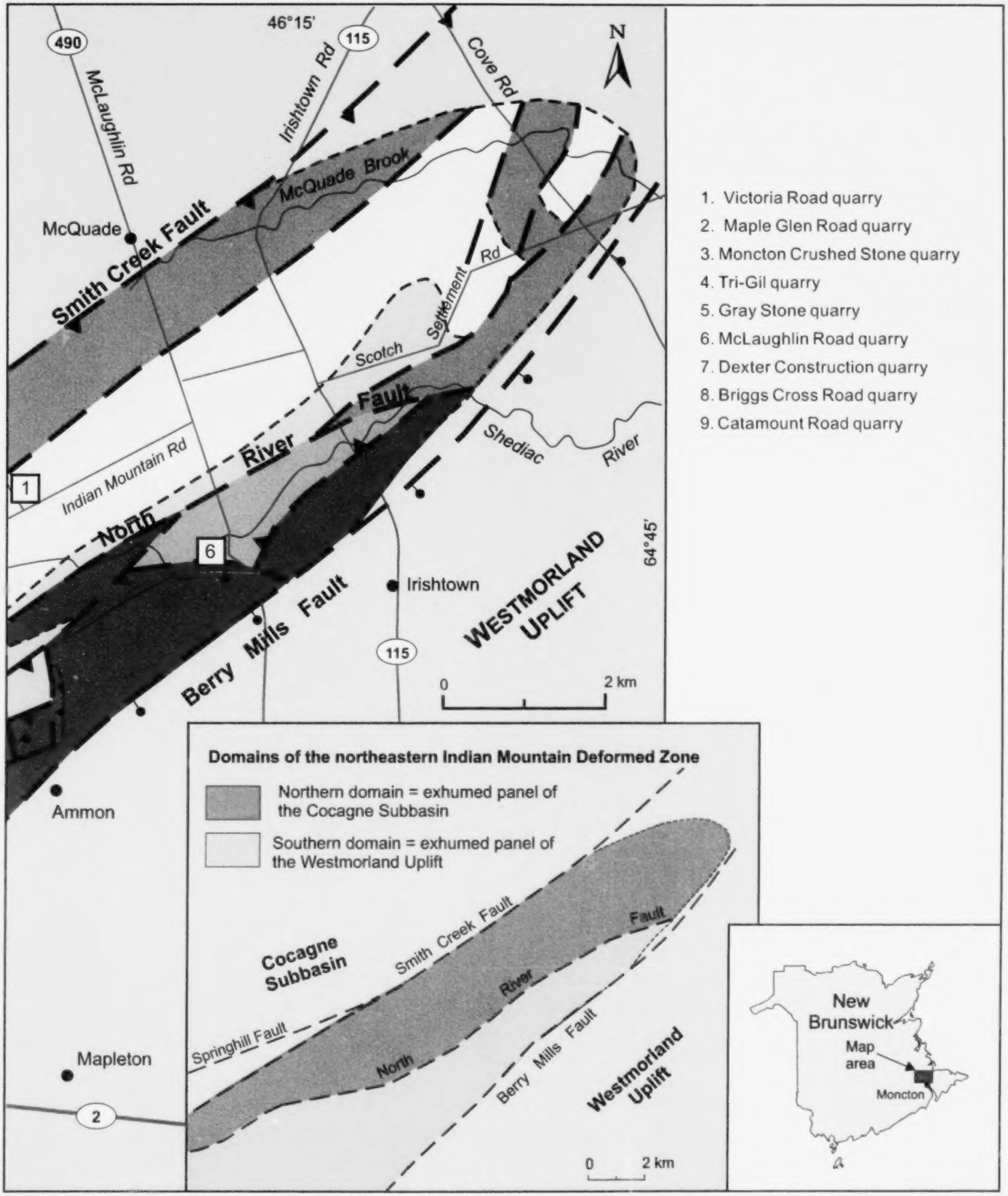
46°15'
490
115
McLaughlin Rd
Irishtown Rd
Cove Rd
N
McQuade Brook
McQuade
Smith Creek Fault
Rd
Settlement
Scotch
North River Fault
Indian Mountain Rd
Shediac River
1
6
64°45'
Irishtown
WESTMORLAND UPLIFT
Berry Mills Fault
115
0
2 km
Ammon
Mapleton
2
1. Victoria Road quarry
2. Maple Glen Road quarry
3. Moncton Crushed Stone quarry
4. Tri-Gil quarry
5. Gray Stone quarry
6. McLaughlin Road quarry
7. Dexter Construction quarry
8. Briggs Cross Road quarry
9. Catamount Road quarry
Domains of the northeastern Indian Mountain Deformed Zone
Northern domain = exhumed panel of the Cocagne Subbasin
Southern domain = exhumed panel of the Westmorland Uplift
Cocagne Subbasin
Smith Creek Fault
Springhill Fault
North River Fault
Berry Mills Fault
Westmorland Uplift
0
2 km
New Brunswick
Map area
Moncton

Figure 10 *(cont'd)*. Map on this page continues eastward from and slightly overlaps *(*see Victoria Road quarry) map on the facing page. The width of the basement slice just north of Ammon is exaggerated to show at this map scale.

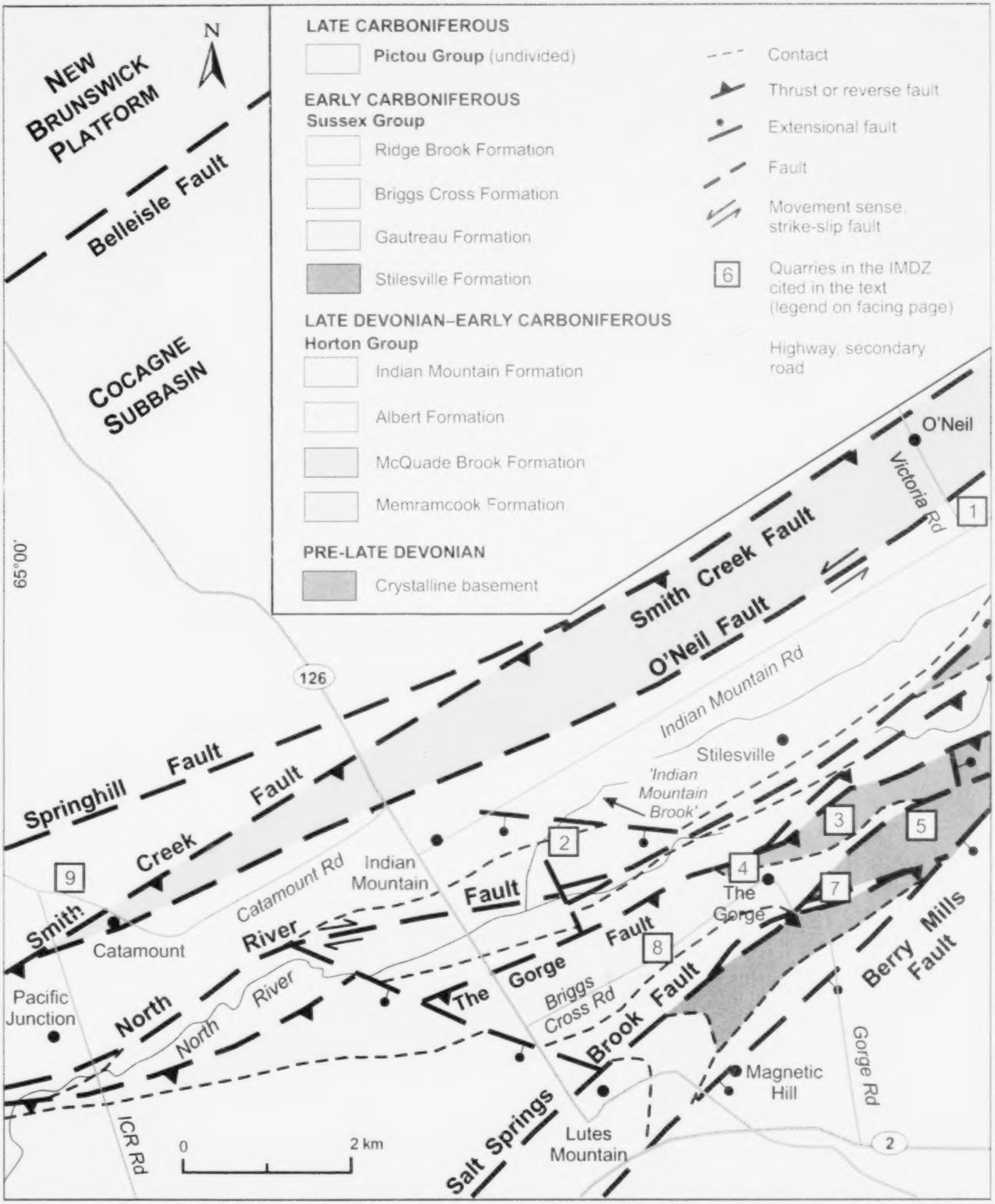
N
NEW BRUNSWICK PLATFORM
Belleisle Fault
COCAGNE SUBBASIN
65°00'
LATE CARBONIFEROUS
Pictou Group (undivided)
EARLY CARBONIFEROUS
Sussex Group
Ridge Brook Formation
Briggs Cross Formation
Gautreau Formation
Stilesville Formation
LATE DEVONIAN–EARLY CARBONIFEROUS
Horton Group
Indian Mountain Formation
Albert Formation
McQuade Brook Formation
Memramcook Formation
PRE-LATE DEVONIAN
Crystalline basement
Contact
Thrust or reverse fault
Extensional fault
Fault
Movement sense, strike-slip fault
6 Quarries in the IMDZ cited in the text (legend on facing page)
Highway, secondary road
O'Neil
Victoria Rd
1
Smith Creek Fault
O'Neil Fault
126
Indian Mountain Rd
Stilesville
'Indian Mountain Brook'
Springhill Fault
Smith Creek Fault
3
5
2
4
7
8
9
Indian Mountain
Catamount Rd
North River Fault
The Gorge
The Gorge Fault
Catamount
Pacific Junction
North River
Briggs Cross Rd
Brook Fault
Berry Mills Fault
Gorge Rd
Magnetic Hill
Salt Springs
Lutes Mountain
ICR Rd
2
0
2 km

Figure 10. Geology map of the northeastern Indian Mountain Deformed Zone (IMDZ) showing exhumed panels of the Cocagne Subbasin and Westmorland Uplift. Modified after St. Peter (2006a, his Fig. 6) and Park and St. Peter (2009, their Fig. 2). *(Caption continues on facing page.)*

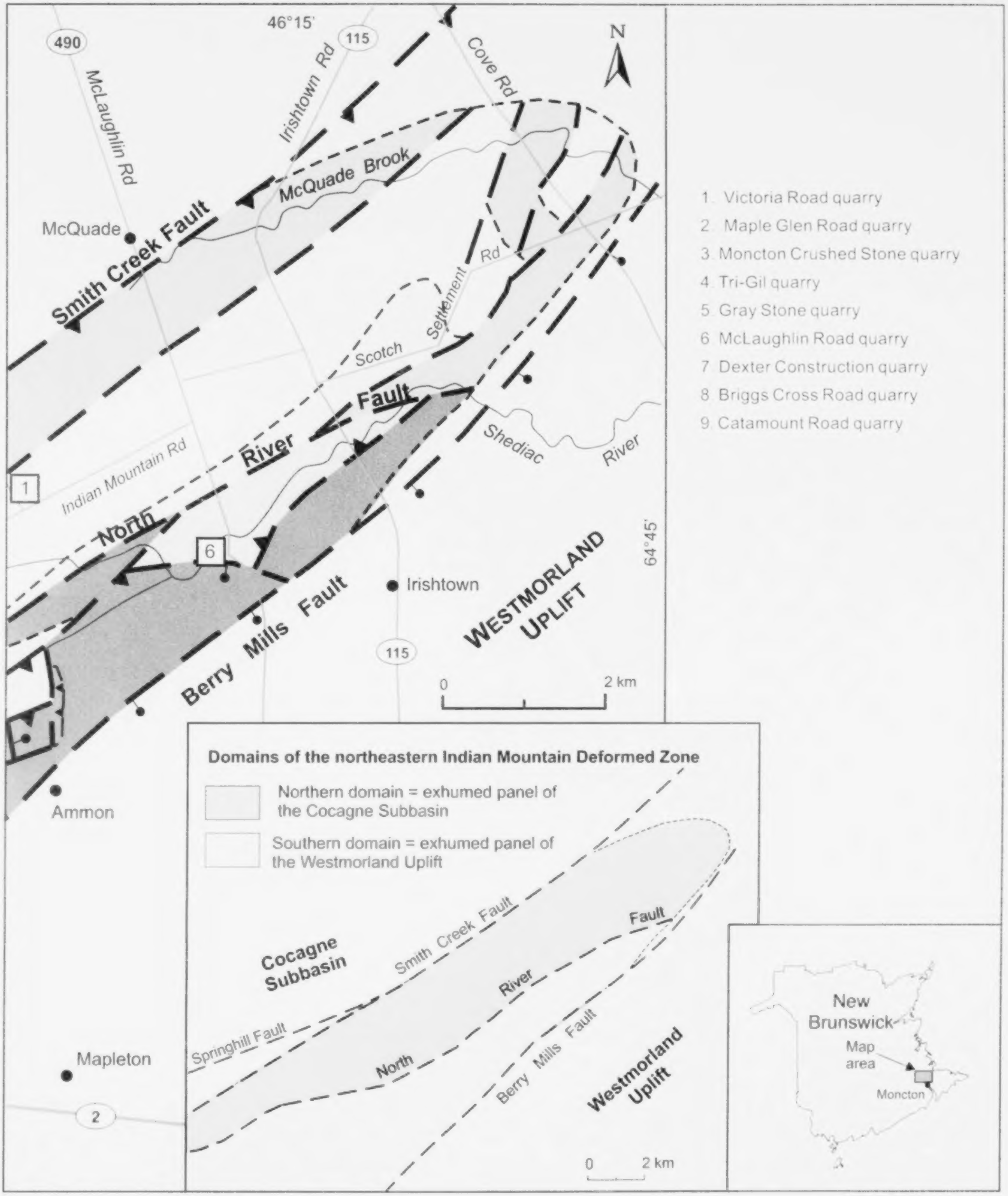
46°15'
490
115
McLaughlin Rd
Irishtown Rd
Cove Rd
N
McQuade Brook
McQuade
Smith Creek Fault
Settlement Rd
Scotch
North River Fault
Shediac River
Indian Mountain Rd
1
6
Irishtown
64°45'
Berry Mills Fault
WESTMORLAND UPLIFT
115
0
2 km
Ammon
Mapleton
2
1. Victoria Road quarry
2. Maple Glen Road quarry
3. Moncton Crushed Stone quarry
4. Tri-Gil quarry
5. Gray Stone quarry
6. McLaughlin Road quarry
7. Dexter Construction quarry
8. Briggs Cross Road quarry
9. Catamount Road quarry
Domains of the northeastern Indian Mountain Deformed Zone
Northern domain = exhumed panel of the Cocagne Subbasin
Southern domain = exhumed panel of the Westmorland Uplift
Cocagne Subbasin
Smith Creek Fault
Springhill Fault
North River Fault
Berry Mills Fault
Westmorland Uplift
0
2 km
New Brunswick
Map area
Moncton

Figure 10 *(cont'd)*. Map on this page continues eastward from and slightly overlaps (see Victoria Road quarry) map on the facing page. The width of the basement slice just north of Ammon is exaggerated to show at this map scale.

CHAPTER 2

STRATIGRAPHY

INTRODUCTION

Thick sequences of Late Devonian–Early Carboniferous strata of the Horton, Sussex, Windsor, and Mabou groups in southeastern New Brunswick occur in four depocentres: the Cocagne, Moncton, Sackville and Cumberland subbasins (Fig. 6, 9). Thinner or condensed sequences of Windsor and Mabou successions lie adjacent to the subbasins on the margins of the Caledonia, Westmorland, and Hastings uplifts. The subbasins are extensional or transtensional depocentres and represent early phases of Maritimes Basin evolution. The stratigraphic successions from the Horton Group through the Mabou Group in each subbasin are roughly similar (Fig. 9), suggesting that the depocentres underwent comparable tectonic and paleoclimatic histories. The Late Carboniferous Cumberland and Pictou groups form a cover sequence that unconformably overlies the older subbasins and partly to completely buries the adjoining uplifts. The Late Carboniferous succession consequently represents a late sag phase of Maritimes Basin morphology (Fig. 6; Bradley 1982).

This chapter describes the lithostratigraphy and biostratigraphy for each of the 26 late Paleozoic geological formations depicted on the New Brunswick portion of the six map areas covered by this report (Fig. 2; 9). The chapter concludes with notes on the small wedge of Mesozoic strata of the Fundy Group at Waterside (Plate 6).

HORTON GROUP

The Horton Group in the report area (Fig. 8) comprises a very thick conformable succession of Late Devonian–Early Carboniferous (early to middle Tournaisian) alluvial and lacustrine strata. It sits unconformably on crystalline basement and is unconformably overlain by either late Tournaisian redbeds of the Sussex Group or younger Carboniferous groups of marine carbonates and evaporites and terrestrial clastic rocks. In ascending order, the Horton Group consists of the Memramcook, McQuade Brook, Albert, Steeves Mills (new name), and Indian Mountain formations. The basal Memramcook Formation comprises mostly coarse-grained redbeds, and the McQuade Brook Formation consists of red and grey sandstone, siltstone, and mudstone. The Albert Formation is made up of fluvial and lacustrine sandstone, mudrocks, and organic-rich shale together with minor dolostone, limestone, and conglomerate. The Steeves Mills Formation comprises red and grey, fluvial, coarse to fine clastics, and minor lacustrine tongues, whereas the Indian Mountain Formation is a unit of green and red sandstone, siltstone, and shale.

The name 'Horton Bluff Series' was given by Dawson (1873) to the predominantly grey terrestrial strata below the marine beds (basal carbonate) of the Windsor Group in recognition of the excellent section at Horton Bluff near the mouth of Avon River, Kings County, Nova Scotia. Bell (1929) renamed the succession as 'Horton Series,' dividing it into the basal, mainly grey, Horton Bluff Formation and the overlying, mainly red, Cheverie Formation. Both formational names are still used in mainland Nova Scotia. Murray (1960) documented the most continuously exposed section of Horton rocks in the Maritimes Basin along Southwest Mabou River in western Cape Breton Island, where the Horton strata lie with pronounced unconformity on Neoproterozoic granitoid rocks (Keppie 1979). Murray (1960) divided the group there into three formations: a coarse, mainly red basal unit, the Craignish Formation; a fine-grained, exclusively grey middle sequence, the Strathlorne Formation; and a fine- to coarse-grained, red and grey upper unit, the Ainslie Formation.

Prior to Murray's work in Cape Breton Island, Gussow (1953) had recognized an essential three-part stratigraphy to the Horton Group in the Moncton Subbasin of New Brunswick: 1) a red, clastic basal sequence, 2) a grey, mainly fine-grained, oil shale-bearing medial unit, and 3) a red, fine and coarse upper sequence. As in Cape Breton and elsewhere in the Maritimes Basin, the Horton Group in New Brunswick lies with angular unconformity on pre-Late Devonian crystalline basement.

Figure 9 shows the surface and subsurface presence of the Horton formations in the subbasins and on adjacent uplifts. Surface exposures of the Horton Group (Plates 3, 4) are limited to

- the northern part of the Indian Mountain Deformed Zone (Fig. 10);
- the southern margin of the Moncton Subbasin adjacent to the Caledonia Uplift between Albert Mines in the east and Sweet Mountain in the west (Fig. 8), and
- inliers along Petitcodiac River at Stoney Creek, Downing Creek, and Boudreau Village and along Memramcook River at Memramcook and Upper Dorchester (Fig. 8).

In the Cocagne Subbasin (Fig. 6), the Memramcook, McQuade Brook and possibly Albert formations of the Horton Group are known from gas and oil exploration wells. In the Sackville Subbasin, the Albert Formation is exposed south of the Dorchester Fault at Upper Dorchester (Plate 4), and the older McQuade Brook and Memramcook formations were intersected in Well 716, located 2 km northeast of Woodhurst. ***(See Appendix 1 for details about this and all other numbered wells cited in Chapter 2.)*** Horton rocks are not exposed at surface in the Cumberland Subbasin of either New Brunswick or Nova Scotia (Fig. 6, 9). In Nova Scotia, however, the subsurface presence of the Horton Group is interpreted from seismic reflection profiles (Ryan and Boehner 1994). It thus seems reasonable to assume that the Horton may also exist in the subsurface in the New Brunswick part of the Cumberland Subbasin.

Memramcook Formation

Author: Norman (1941a, 1941b).

Type Section: A specific type section was not defined by Norman but, on the basis of the name, was assumed to be the most continuous exposures along Stony Creek northeast of Memramcook. Popper (1965) subsequently proposed those exposures as the type section. Because of structural complications in the area, the type section (Fig. 11) is designated herein as being from near the mouth of Stony Creek, Westmorland County (NTS 21 I/02; Plate 3) up the stream to where the lowest beds are exposed. The fairly consistent south-southwest dip of the beds there suggests the section was unlikely to have been disturbed by significant faults. Popper (1965, p. 55–60) provides a detailed account of the type section. A brief description of the type section outcrops is given in Table 2.

Table 2. Description of outcrops in type section of Memramcook Formation, Stony Creek.

O	T	Description
Upper concealed interval	650	Section concealed from upper beds of outcrop 13 to McQuade Brook Formation; contact is estimated, assuming that 1) the dip is 50°, 2) the Memramcook–McQuade Brook formational contact is approximately as on Plate 3 and Fig. 11, and 3) no faults disturb the section.
Outcrop 13	5	Grey, lithic feldspathic arenite in fining-upward sequences from very coarse-grained, massive beds to medium-grained, parallel-laminated, flaggy beds to medium-grained beds with cross-laminations or small-scale planar cross-beds. Finer grainer beds contain abundant plant fragments and spores; see spore locality F in St. Peter and Johnson (2009). Paleocurrent toward 175°.
Concealed	75	–
Outcrop 12	20	Same fining-upward sandstone sequences as at outcrop 13, but with a 10 m thick interval of reddish brown micaceous siltstone and mudstone. Paleocurrent toward 22°.
Concealed	150	–
Outcrop 11	4	Grey to maroon-grey, coarse-grained, lithic feldspathic arenite sharply overlain by 1.5 m of green siltstone, erosively overlain by pebbly, coarse-grained, normally graded, lithic feldspathic arenite, gradationally overlain by parallel-laminated flaggy arenite. Outcrop buried by TCH (Fig. 11).
Concealed	40	–
Outcrop 10	3	Same sandstone beds as outcrop 11.
Concealed	20	–
Outcrop 9	6	Grey to maroon-grey, medium- to coarse-grained, lithic feldspathic arenite in fining-upward cycles of small-scale trough cross-beds overlain by parallel beds overlain by low angle planar cross-beds overlain by parallel-laminated beds. Paleocurrent toward 150°.
Concealed	20	–
Outcrops 8, 7, 6	22	Same fining-upward sequences as at outcrop 9. One sequence at outcrop 6 has a basal, well-rounded, pebble conglomerate bed 30 cm thick with an erosive base into underlying trough cross-bedded sandstone. Coarse-grained sandstones locally have red mudstone intraclasts. Finer grained beds at outcrop 8 have abundant plant fragments. Paleocurrent at outcrop 7 is toward 157°.
Concealed	45	–
Outcrops 5,4	20	Same fining-upward sandstone sequences (1–2 m thick) as at outcrop 9. Basal part of some cycles at outcrop 5 comprises lenticular beds (0.5–1 m thick) of well-rounded, pebble–cobble conglomerate. One cycle is capped by 3 m of reddish brown and grey, micaceous, calcareous siltstone. Paleocurrent at outcrop 4 is toward 160°.
Concealed	25	–
Outcrop 3	3	Thickly interbedded, pebbly, coarse-grained, lithic feldspathic arenite and coarse-grained, lithic feldspathic arenite.
Concealed	25	–
Outcrop 2	2	Same pebbly and coarse-grained arenite as outcrop 3.
Concealed	15	–
Outcrop 1	2	Medium-grained, lithic feldspathic arenite.
Lower concealed interval	?	Original thickness of concealed Memramcook section below outcrop 1 and above underlying basement is impossible to determine because boundary is a fault.
Basement		Fault contact between basement and Memramcook exposed in quarry ~1 km NW of Stony Creek (Fig. 11).

O = outcrop number and concealed intervals in Figure 11. Concealed interval thicknesses were determined from bedding dips above and below concealed intervals and by map-scale interpolations. **T** = thickess of exposed or concealed beds in metres. Section thicknesses at individual outcrops were visually estimated, not measured.

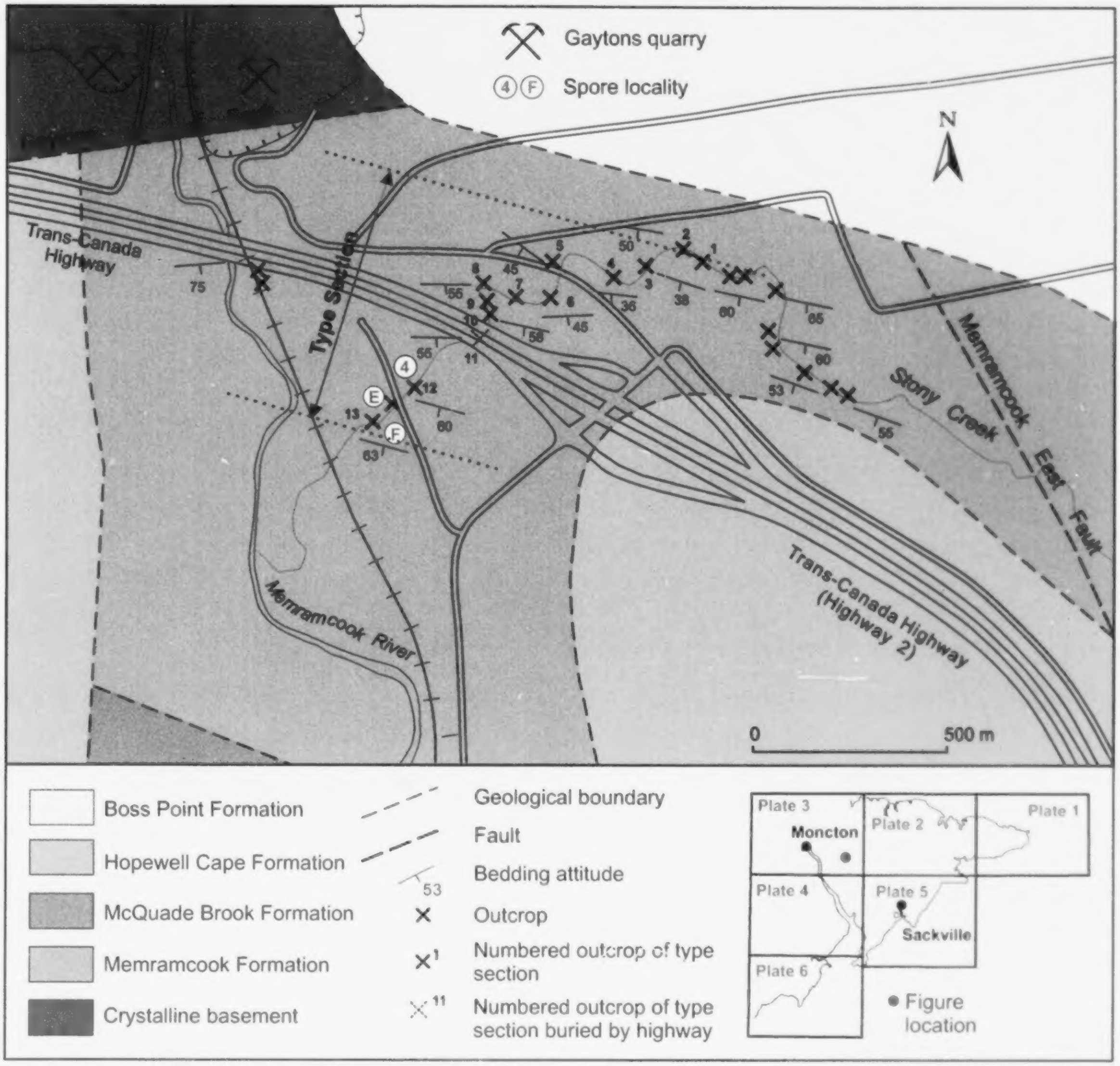
Gaytons quarry
④Ⓕ Spore locality
N
Trans-Canada Highway
Type Section
Memramcook River
Stony Creek
Memramcook East Fault
Trans-Canada Highway (Highway 2)
0
500 m
75
55
45
5
50
2
1
4
3
38
60
65
8
9
7
6
36
10
58
45
11
56
4
12
E
13
F
60
63
53
55
Boss Point Formation
Hopewell Cape Formation
McQuade Brook Formation
Memramcook Formation
Crystalline basement
Geological boundary
Fault
Bedding attitude
53
Outcrop
Numbered outcrop of type section
Numbered outcrop of type section buried by highway
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 11. Type section of the Memramcook Formation at Stony Creek, southeastern New Brunswick. Numbered outcrops are described in Table 2.

Definition and Description: The Memramcook Formation is a Late Devonian (Famennian)–Early Carboniferous (early to middle Tournaisian), predominantly coarse-grained redbed sequence lying unconformably on crystalline basement and conformably succeeded by early Tournaisian fine-grained redbeds of the McQuade Brook Formation. It represents the first record of sedimentation in the Maritimes Basin in southeastern New Brunswick.

A general description of the Memramcook is given by Norman (1932, 1941a, 1941b), Gussow (1953), Carter and Pickerill (1985a), and St. Peter (1992, 1993). Popper (1965) provides the most complete and detailed account of the formation. The formation shows considerable variation in bedforms and composition from one area to another. It comprises polymictic conglomerates, granular to fine-grained sandstones, siltstone, mudstone, and minor calcrete.

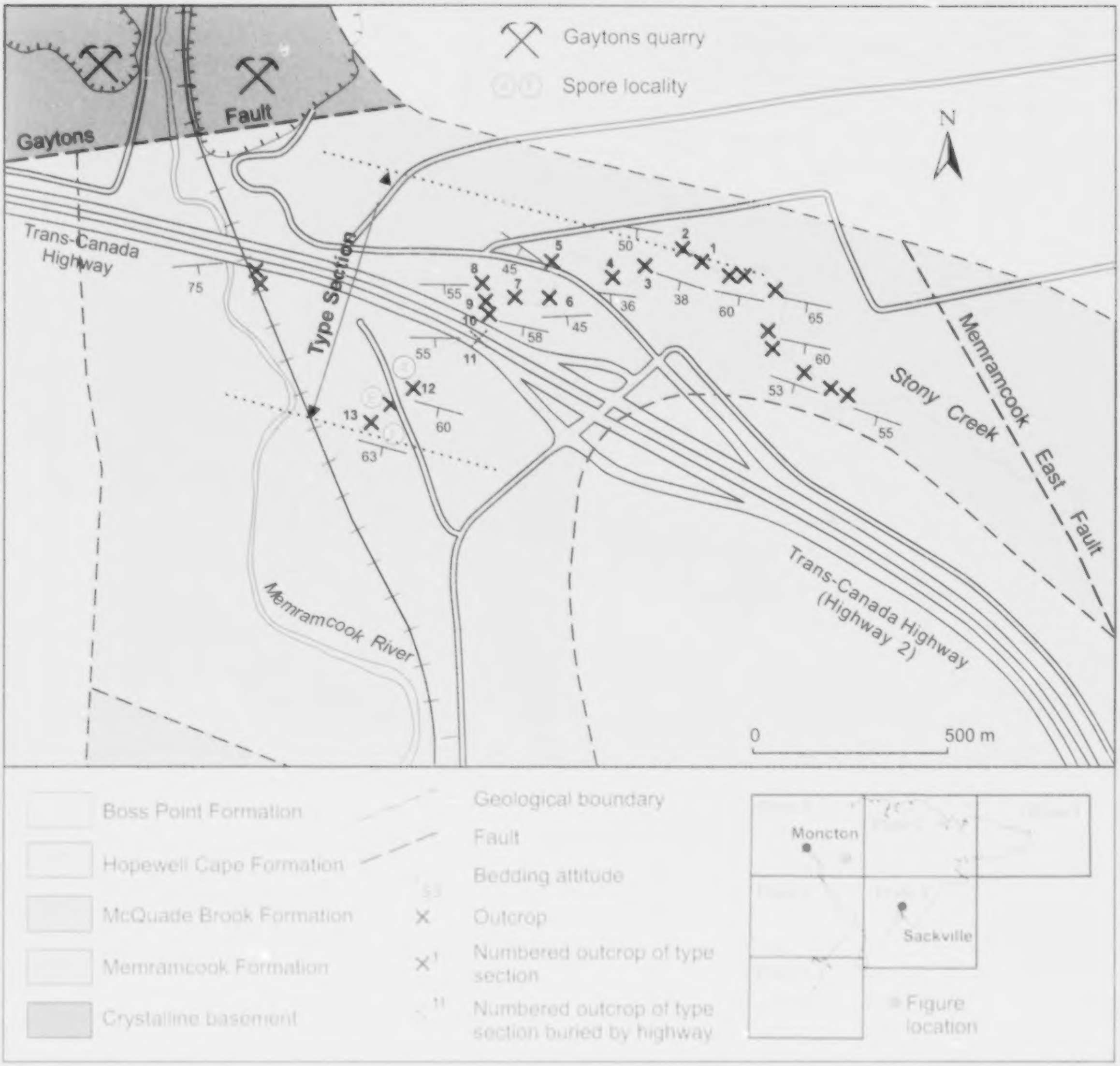
Gaytons quarry
Spore locality
N
Gaytons Fault
Trans-Canada Highway
Type Section
Memramcook River
Stony Creek
Memramcook East Fault
Trans-Canada Highway (Highway 2)
0
500 m
Boss Point Formation
Hopewell Cape Formation
McQuade Brook Formation
Memramcook Formation
Crystalline basement
Geological boundary
Fault
Bedding attitude
Outcrop
Numbered outcrop of type section
Numbered outcrop of type section buried by highway
Moncton
Sackville
Figure location

Figure 11. Type section of the Memramcook Formation at Stony Creek, southeastern New Brunswick. Numbered outcrops are described in Table 2.

Definition and Description: The Memramcook Formation is a Late Devonian (Famennian)–Early Carboniferous (early to middle Tournaisian), predominantly coarse-grained redbed sequence lying unconformably on crystalline basement and conformably succeeded by early Tournaisian fine-grained redbeds of the McQuade Brook Formation. It represents the first record of sedimentation in the Maritimes Basin in southeastern New Brunswick.

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In the type section at Stony Creek in the Moncton Subbasin (Fig. 11), the Memramcook Formation is characterized by 1 m to 3 m thick, fining-upward cycles of grey to reddish grey, fine- to coarse-grained, lithic feldspathic sandstone. The coarser grained beds near the base of the cycles are either massive or trough cross bedded, whereas the upper parts of the sand cycles show small-scale trough cross-beds (less commonly planar cross-beds), and ripple or parallel laminations. Some sand beds carry angular intraformational red mudstone clasts. Locally, the finer grained beds near the top of the sand intervals contain abundant comminuted plant detritus and plant fragments. In the lower part of the type section, the base of some fining-upward cycles begins with polymictic, granule to pebble conglomerate or rarely cobble conglomerate. The conglomerate occurs in parallel to lenticular beds 30 cm to 100 cm thick. The basal contacts of the conglomerate beds are either sharp or erosive into the underlying finer lithotype of the preceding cycle. Toward the upper part of the type section, the tops of some fining-upward cycles comprise reddish brown to rarely greyish green siltstone and mudstone intervals up to 10 m thick.

The type section of the Memramcook Formation shows a fining-upward trend. Coarse conglomerate beds are more abundant in the northern, lower part of the formation. For example, just northwest of the type section, on the south face of the eastern Gaytons quarry (Fig. 11; Plate 3), the Memramcook Formation is in contact with basement rock along the Gaytons Fault. There, an interval of polymictic, pebble to small cobble conglomerates 5 m thick and a bed of pebbly coarse sandstone 3 m thick are interbedded with finer sandstones and mudstones. Similar but trough cross-bedded pebbly sandstone dipping 75°S appears in finer sandstones on the east side of the railway and immediately south of the Trans-Canada Highway (Fig. 11).

The clasts in the conglomerate beds are typically rounded. They comprise abundant pink granite and pink feldspar as well as less common quartzite, rhyolite, mafic volcanic rock, metasandstone, hornfelsic or cherty dark grey metasiltstone, mylonitic granite, paragneiss, and marble. The pink granite and feldspar clasts are without doubt derived from the adjacent basement granite that contains feldspar megacrysts up to 5 cm in length. The paragneiss and marble grains also imply a northerly source for the Memramcook detritus, supporting the argument by Barr and White (1991) that the basement flooring the Moncton Subbasin and constituting the Westmorland Uplift consists of gneisses, marbles, and granitoids of the Brookville terrane. Popper (1965) noted the common occurrence of what he called "limestone" (probably marble) in the coarser Memramcook beds but could not account for its source. A northerly source for sediments in the Memramcook area is also supported by the fact that paleocurrent determinations on cross-beds in the type section give a mean transport direction toward 158° (St. Peter 1992).

The authors have not studied the Memramcook Formation east of the type section along the eastern reaches of Stony Creek and near the mouth of Prairie Brook. Shallow boreholes near the granite inlier at the mouth of Prairie Brook indicate that the Memramcook in this area comprises significant granite-clast conglomerate interbedded with gritty sandstone and mudstone (D.V. Venugopal, pers. comm. to CSP, 1996). This supports Popper's (1965) description of the formation and further demonstrates that the Memramcook is coarsest near its base.

The Memramcook Formation also appears in the Indian Mountain Deformed Zone north of Irishtown along Shediac River in the abandoned McLaughlin Road quarry near the river (Fig. 10). As in the type section, the formation in the Shediac River area consists of fining-upward cycles of polymictic conglomerate, lithic to feldspathic sandstone, and minor siltstone and shale (Fig. 12a, 12b; Park and St. Peter 2009). Each lithotype varies in thickness from centimetres to several metres. The conglomerate intervals are pinkish to reddish brown (rarely greyish green) and carry granule- to cobble-sized clasts of mainly granite and cataclastic granite with minor mafic plutonic, volcanic, and metasedimentary rocks. The clasts are closely comparable with basement rocks exposed at The Gorge (Fig. 10) about 6 km to the southwest (Park and St. Peter 2009). The siltstone and shale intervals in the Memramcook along Shediac River range from reddish brown to green or grey and are up to 5 m or more in thickness. Pedogenic carbonate nodules appear in some of the redbeds, and plant detritus is locally present in the grey strata.

A condensed section of the Memramcook Formation lies on the Caledonia basement north of Ferndale (Plate 4). The exposures there suggest that the formation comprises mostly pink to red, polymictic, pebble to cobble conglomerate with minor interbeds of red, muddy, granular lithic sandstone and red, muddy, medium- to coarse-grained lithic sandstone. The clasts in the conglomerates are commonly matrix-supported, and the matrix is typically muddy grit. Clast types vary from outcrop to outcrop. Some beds are dominated by granite clasts, whereas others contain abundant angular clasts of schistose metasedimentary, felsic, and mafic volcanic rocks. The clasts are comparable with local rocks in the Caledonia Uplift.

The Memramcook Formation west of Sweet Mountain and just south-southwest of Parkindale (Fig. 6; Plate 4) is poorly exposed in small outcrops along and near Little River. The formation there is composed predominantly of reddish brown, polymictic, pebble to cobble conglomerate; reddish brown, coarse-grained to granular lithic sandstones; and minor red, fine- to medium-grained sandstone and mudstone. The conglomerate clasts are typically subrounded and up to 4 cm in diameter. About 3 km west of Little River, adjacent to the Caledonia basement, the conglomerate carries clasts of granite and lesser gabbro up to 75 cm in diameter. The granite detritus is likely derived from the Pointe Wolfe River Pluton that lies immediately south in the Caledonia Uplift (McLeod et al. 1994). Popper (1965) records the following clast content from the Memramcook conglomerate along Pollett River, 9 km southwest of Little River: 90% aphanitic, porphyritic, and tuffaceous volcanic rock; 8% granite and granodiorite; and 2% metasedimentary fragments. These clasts are undoubtedly derived from the dominantly volcanic and metasedimentary Coldbrook Group of the adjacent Caledonia Uplift (McLeod et al. 1994). In this area, as elsewhere, local basement highlands are the source of Memramcook detritus.

Distribution and Thickness: The Memramcook Formation is exposed at its type section along Stony Creek in the easternmost Moncton Subbasin. It also appears north of Irishtown along Shediac River in the Indian Mountain Deformed Zone (Fig. 10). On the western edge of the report area, the Memramcook Formation lies unconformably on pre-Late Devonian basement between Ferndale and Prosser Brook and in fault contact with the McQuade Brook and Albert formations just west of Sweet Mountain (Plate 4). The Memramcook Formation exists in the subsurface in the Monteagle area of the Cocagne Subbasin west of Plate 3 (Fig. 6; St. Peter 2006a). On the southern flank of the Westmorland Uplift, the formation was cut in several wells west of the Stoney Creek Field (Fig. 13, 14). In the Sackville Subbasin, polymictic conglomerate of the Memramcook Formation was intersected in 2001 at a depth of 3165 m in Well 716 just northeast of Woodhurst (Plate 5), the first-ever indication of the formation in that subbasin.

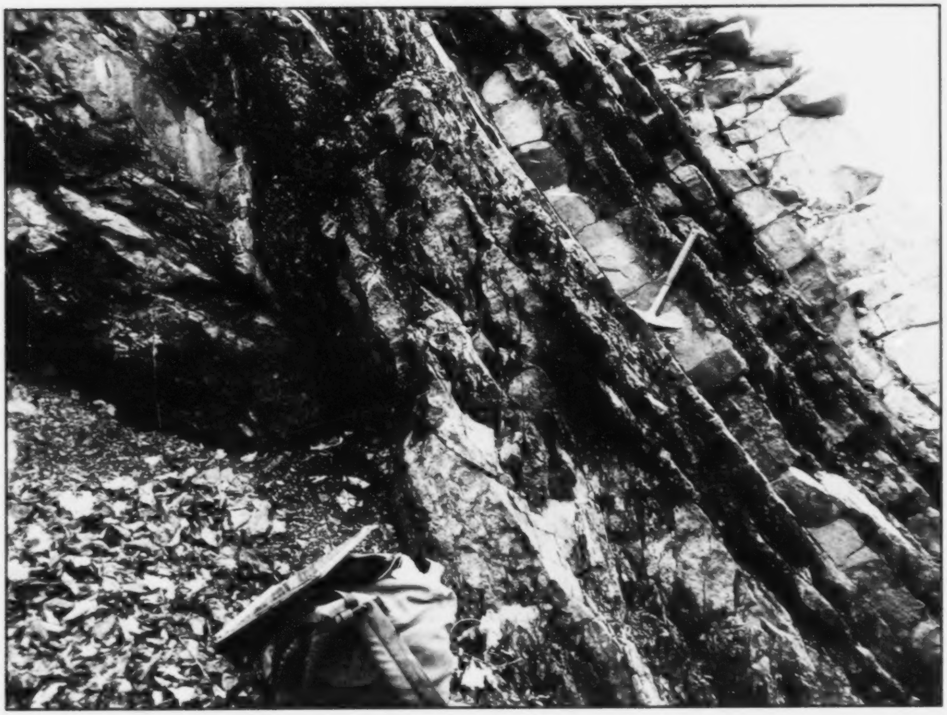


Figure 12a. Fining-upward cycles of pinkish brown polymictic conglomerate and sandstone, and dark grey siltstone and shale of the Memramcook Formation, McLaughlin Road quarry.

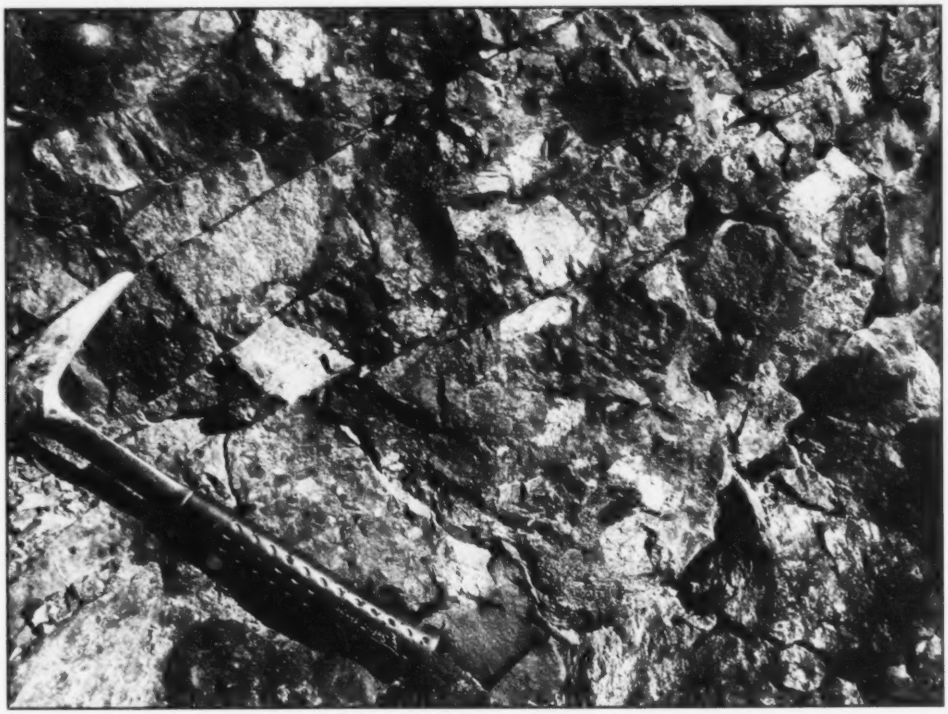


Figure 12b. Closeup view of outcrop in Figure 12a. Shows clast-supported polymictic conglomerate with subangular to rounded pebbles of pink granite, brown to pink felsic volcanic rock, and dark grey to greenish grey metasedimentary rocks in a muddy grit matrix.

The thickness of the Memramcook Formation in the type section is greater than 1200 m (Table 2). The total thickness there is impossible to assess because of 1) uncertainties about the exact location of the upper contact with the McQuade Brook Formation, and 2) the unknown thickness of the lower part of the section 'missing' along the Gaytons Fault (Fig. 11). North of Irishtown, the Memramcook is in fault contact with younger rocks of the Horton and Sussex groups (Fig. 10). The bounding faults and minor folds and faults within the beds prevent an estimate of thickness at that location. About 3 km west of Sweet Mountain (west of Plate 4), the Memramcook Formation lies unconformably on pre-Late Devonian basement (Park et al. 2007, their Fig. 3b), and upper beds of the formation are faulted out by the Gordon Falls and Gowland Mountain faults. Consequently, a thickness estimate of the complete formation cannot be made, although the exposed part of the section exceeds 500 m.

North of Ferndale, the Memramcook section is highly condensed. The shallow dip of strata and narrow outcrop width between the basement and overlying McQuade Brook Formation suggest the formation is only a few tens of metres thick in that area. Similarly, an exploration test of the Albert Formation in Well 200 at Rosevale encountered the Memramcook Formation at a depth of 650.6 m, although only 6.7 m of the formation was drilled before the well was discontinued. Adjacent boreholes drilled by the federal Department of Mines for oil shale assessment in 1942 (Ells 1948) intersected rocks of the Albert Formation sitting on basement, which demonstrates that the Memramcook Formation is either absent or very thin in the Rosevale area. In the subsurface about 5 km northwest of the Stoney Creek Field (Fig. 6), in Well 254, the Memramcook rests on basement and shows a drill thickness of 525 m (Fig. 14). About 11 km west of there, 3 km west of Turtle Creek in Well 319, the formation lies unconformably below the Windsor Group and exceeds 500 m in thickness (Fig. 13).

Lower and Upper Boundaries: The lower depositional boundary of the Memramcook Formation is not exposed in the report area. However, the great differences in ages between the underlying basement rocks and the Late Devonian–Early Carboniferous Memramcook Formation imply a significant regional unconformity at the base of the formation. The existence of that unconformity is best demonstrated between Ferndale and Prosser Brook (Plate 4), where the shallow dip of Memramcook beds and the apparent topographic control on the sinuous boundary with the basement indicate the contact is likely undisturbed by faults.

In the type area, the lowest beds of the formation are in contact with basement granite along the Gaytons Fault, which is exposed in the Gaytons quarry just north of the type section (Fig. 11). North of Irishtown along Shediac River, the Memramcook is in fault contact with all adjacent formations: the McQuade Brook and Indian Mountain formations along the main trace of the North River Fault, and the Stilesville Formation along southern splays of that fault (Fig. 10).

The upper contact of the Memramcook Formation is believed to be conformable with the overlying McQuade Brook Formation. However, no well-exposed section exists revealing the boundary. Numerous seismic reflection profiles in the eastern Moncton Subbasin show no discordance of reflectors within the Horton Group; from this, the Memramcook and McQuade Brook formations are interpreted to be conformable (St. Peter 1992). The Memramcook–McQuade Brook contact was intersected in several wells in the southeastern Moncton Subbasin (St. Peter 1992). Evidence from the well intersections, supplemented by field data, enables the formational boundary to be placed (on ascending the section) at the top of the

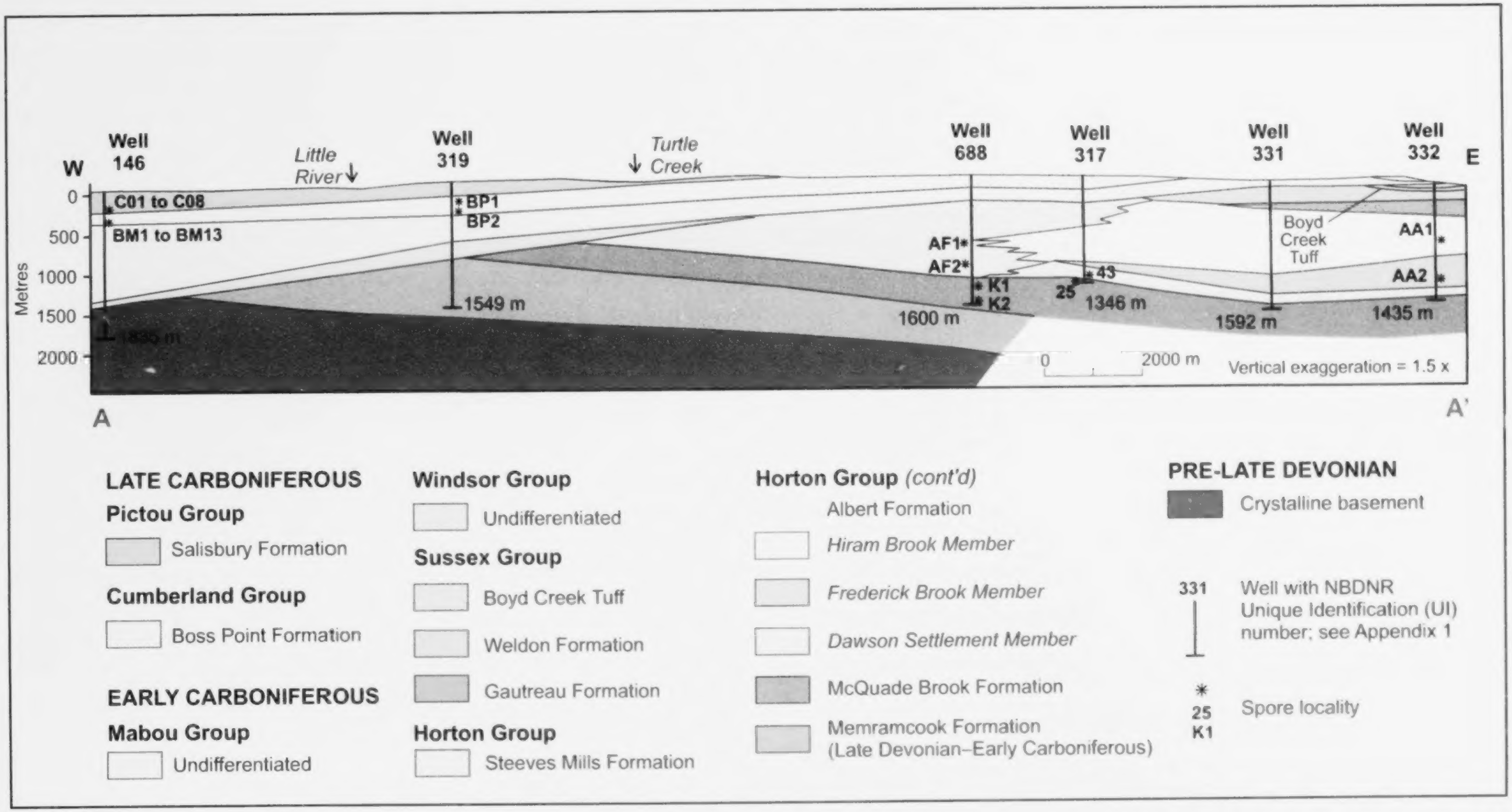

W
Well 146
Little River
Well 319
Turtle Creek
Well 688
Well 317
Well 331
Well 332
E
0
500
1000
1500
2000
Metres
C01 to C08
BM1 to BM13
BP1
BP2
1549 m
1835 m
AF1
AF2
K1
K2
1600 m
25
43
1346 m
Boyd Creek Tuff
1592 m
AA1
AA2
1435 m
0
2000 m
Vertical exaggeration = 1.5 x
A
A'
LATE CARBONIFEROUS
Pictou Group
Salisbury Formation
Cumberland Group
Boss Point Formation
EARLY CARBONIFEROUS
Mabou Group
Undifferentiated
Windsor Group
Undifferentiated
Sussex Group
Boyd Creek Tuff
Weldon Formation
Gautreau Formation
Horton Group
Steeves Mills Formation
Horton Group (cont'd)
Albert Formation
Hiram Brook Member
Frederick Brook Member
Dawson Settlement Member
McQuade Brook Formation
Memramcook Formation (Late Devonian–Early Carboniferous)
PRE-LATE DEVONIAN
Crystalline basement
331
Well with NBDNR Unique Identification (UI) number; see Appendix 1
25
K1
Spore locality

Figure 13. Longitudinal section A–A' (on Plate 4) reaches from Well 146 at Colpitts Settlement to Well 332 at Petitcodiac River. The Stoney Creek Field is situated in the Albert Formation east of Well 317. Section interpretation is supported by public seismic reflection profiles.

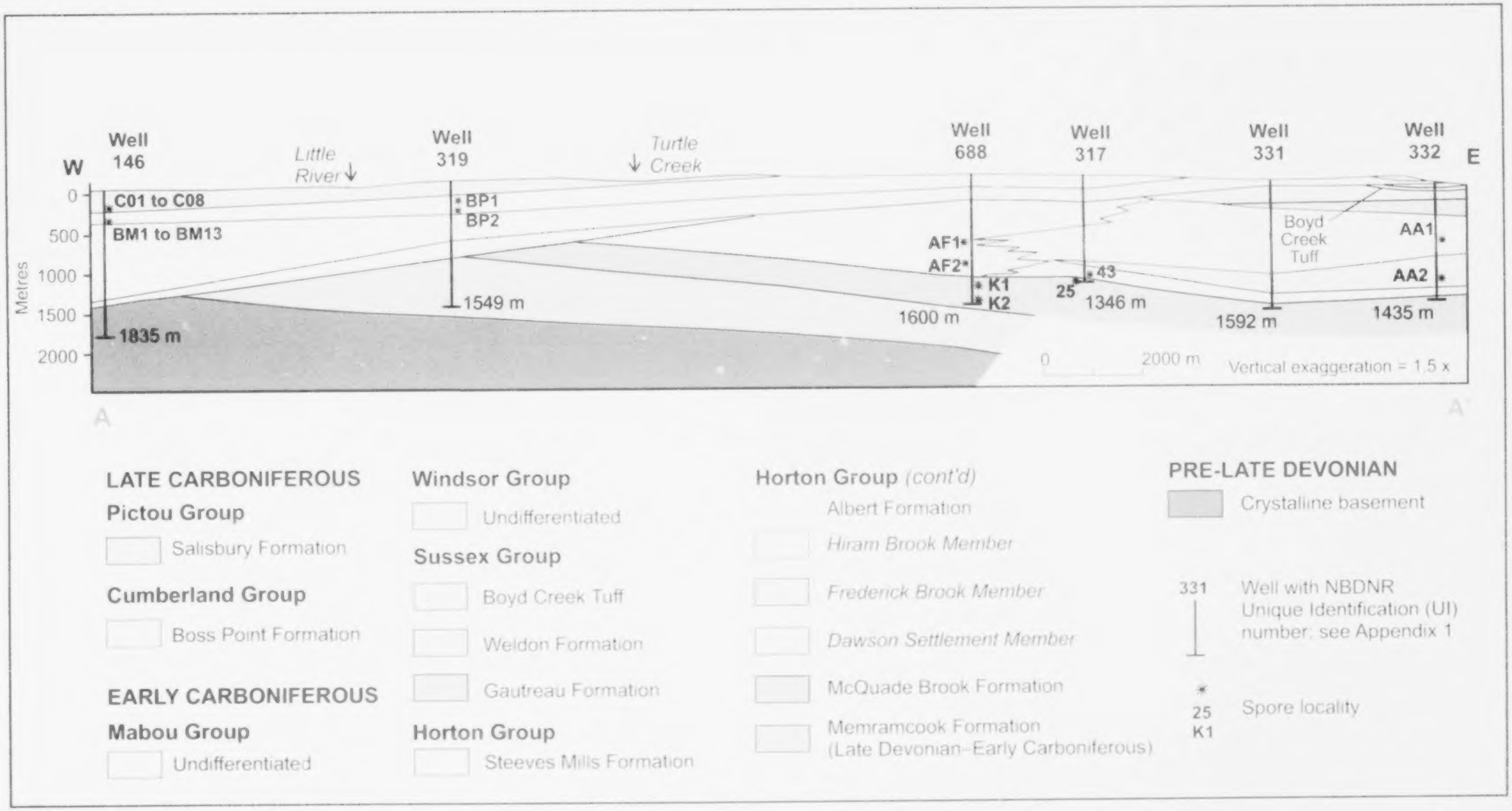

Well 146
W
Little River
Well 319
Turtle Creek
Well 688
Well 317
Well 331
Well 332
E
0
500
1000
1500
2000
Metres
C01 to C08
BM1 to BM13
BP1
BP2
1549 m
1835 m
AF1
AF2
K1
K2
1600 m
43
25
1346 m
Boyd Creek Tuff
1592 m
AA1
AA2
1435 m
0
2000 m
Vertical exaggeration = 1.5 x
A
A'
LATE CARBONIFEROUS
Pictou Group
Salisbury Formation
Cumberland Group
Boss Point Formation
EARLY CARBONIFEROUS
Mabou Group
Undifferentiated
Windsor Group
Undifferentiated
Sussex Group
Boyd Creek Tuff
Weldon Formation
Gautreau Formation
Horton Group
Steeves Mills Formation
Horton Group (cont'd)
Albert Formation
Hiram Brook Member
Frederick Brook Member
Dawson Settlement Member
McQuade Brook Formation
Memramcook Formation (Late Devonian–Early Carboniferous)
PRE-LATE DEVONIAN
Crystalline basement
331
Well with NBDNR Unique Identification (UI) number; see Appendix 1
25
K1
Spore locality

Figure 13. Longitudinal section A–A' (on Plate 4) reaches from Well 146 at Colpitts Settlement to Well 332 at Petitcodiac River. The Stoney Creek Field is situated in the Albert Formation east of Well 317. Section interpretation is supported by public seismic reflection profiles.

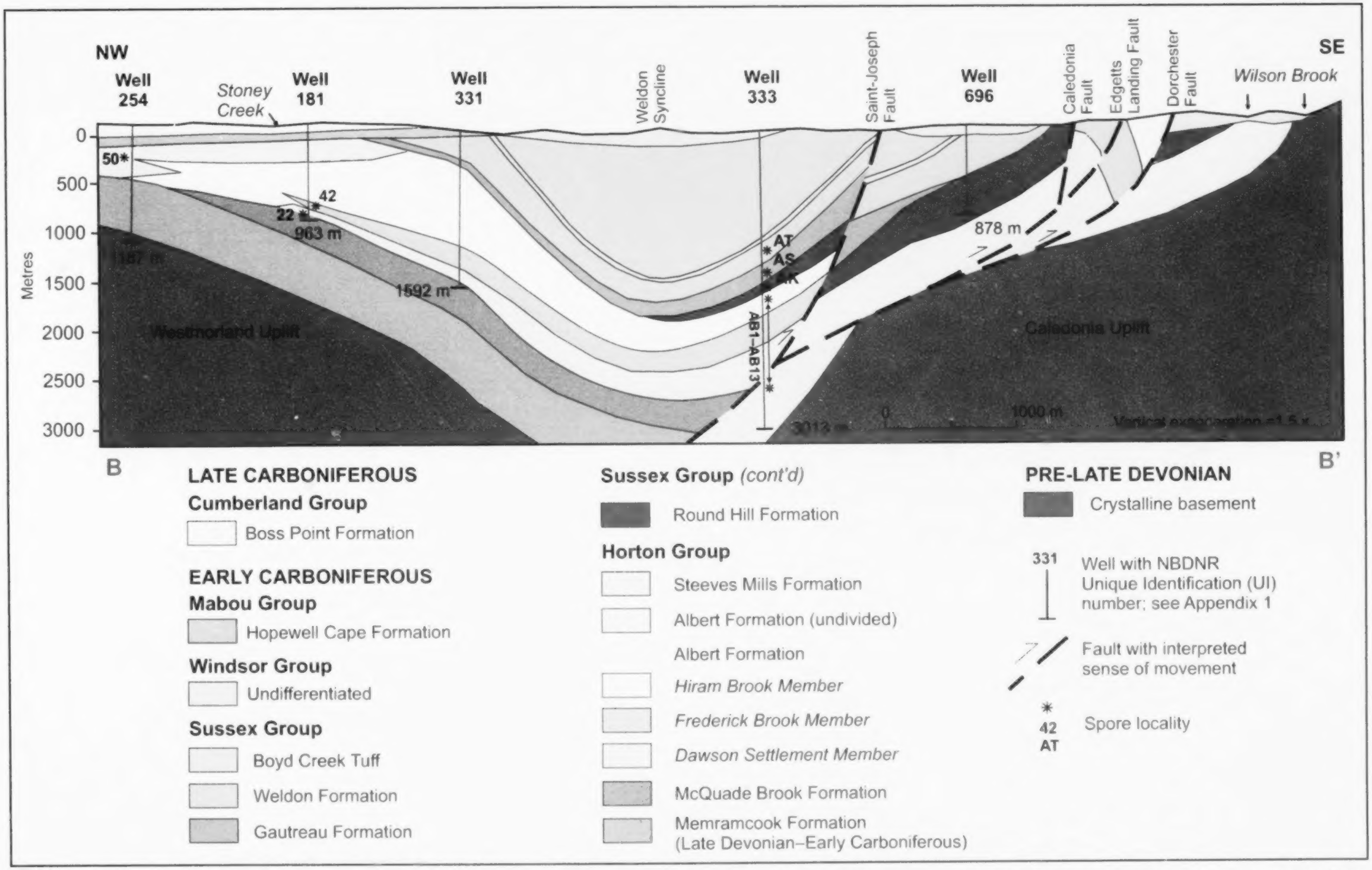

NW
SE
Well 254
Stoney Creek
Well 181
Well 331
Weldon Syncline
Well 333
Saint-Joseph Fault
Well 696
Caledonia Fault
Edgetts Landing Fault
Dorchester Fault
Wilson Brook
0
500
1000
1500
2000
2500
3000
Metres
50*
42
22
963 m
1187 m
1592 m
AT
AS
AK
AB1–AB13
878 m
3013 m
Westmorland Uplift
Caledonia Uplift
0
1000 m
Vertical exaggeration ≈1.5 x
B
B'
LATE CARBONIFEROUS
Cumberland Group
Boss Point Formation
EARLY CARBONIFEROUS
Mabou Group
Hopewell Cape Formation
Windsor Group
Undifferentiated
Sussex Group
Boyd Creek Tuff
Weldon Formation
Gautreau Formation
Sussex Group (cont'd)
Round Hill Formation
Horton Group
Steeves Mills Formation
Albert Formation (undivided)
Albert Formation
Hiram Brook Member
Frederick Brook Member
Dawson Settlement Member
McQuade Brook Formation
Memramcook Formation (Late Devonian–Early Carboniferous)
PRE-LATE DEVONIAN
Crystalline basement
331
Well with NBDNR Unique Identification (UI) number; see Appendix 1
Fault with interpreted sense of movement
42
AT
Spore locality

Figure 14. Cross-section B–B' (on Plate 4) reaches from Well 254 north of Stoney Creek to Wilson Brook. The Stoney Creek Field lies in the Albert Formation between Wells 181 and 331. Section interpretation is supported by seismic reflection profiles. The southern part of the section in subsurface is highly speculative. The Salem Fault is omitted for the sake of clarity.

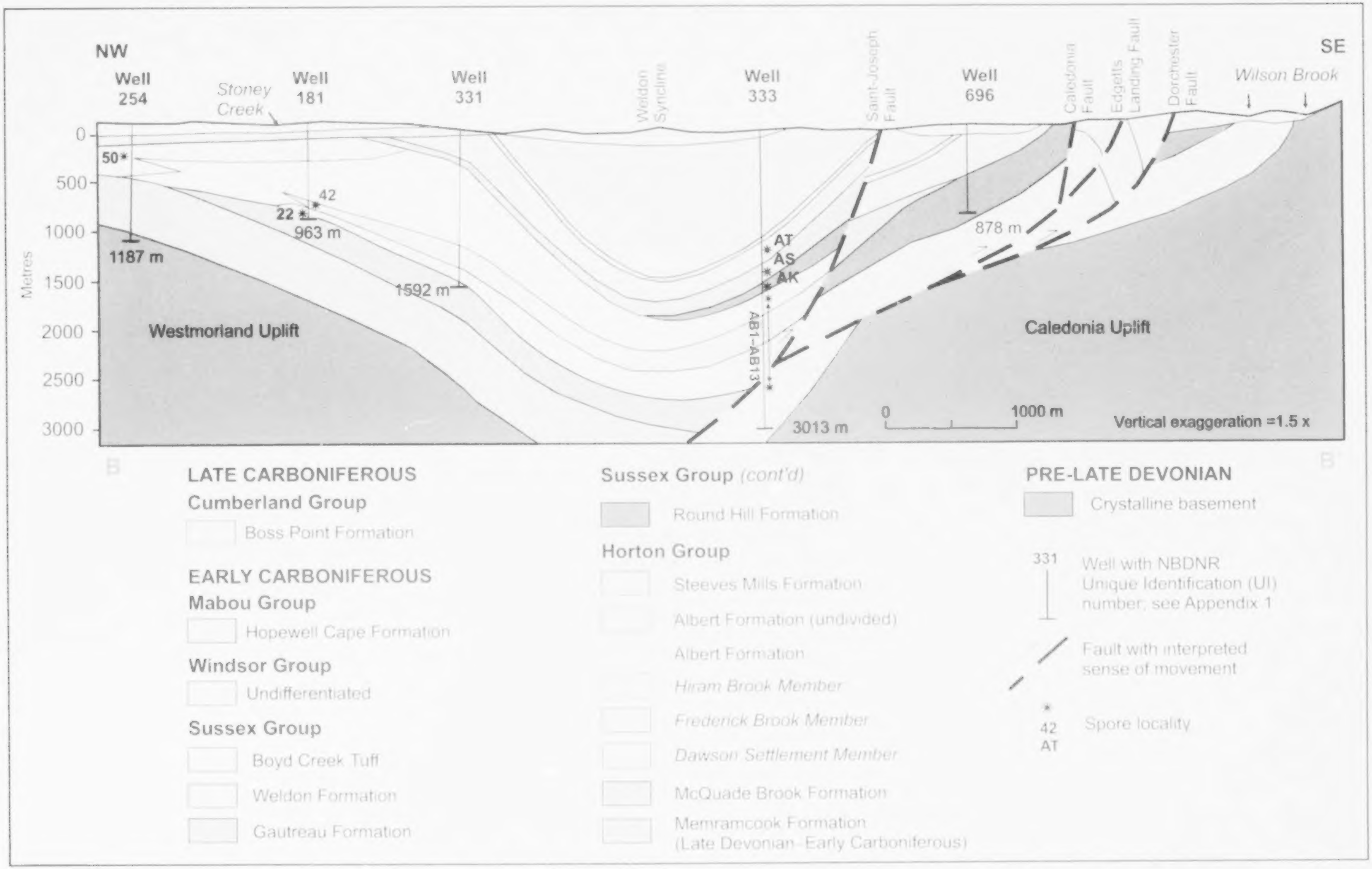

NW
Well 254
Stoney Creek
Well 181
Well 331
Weldon Syncline
Well 333
Saint-Joseph Fault
Well 696
Caledonia Fault
Edgetts Landing Fault
Dorchester Fault
SE
Wilson Brook
Metres
0
500
1000
1500
2000
2500
3000
50
42
22
963 m
1187 m
1592 m
AT
AS
AK
AB1–AB13
878 m
3013 m
Westmorland Uplift
Caledonia Uplift
0
1000 m
Vertical exaggeration =1.5 x
B
B'
LATE CARBONIFEROUS
Cumberland Group
Boss Point Formation
EARLY CARBONIFEROUS
Mabou Group
Hopewell Cape Formation
Windsor Group
Undifferentiated
Sussex Group
Boyd Creek Tuff
Weldon Formation
Gautreau Formation
Sussex Group (cont'd)
Round Hill Formation
Horton Group
Steeves Mills Formation
Albert Formation (undivided)
Albert Formation
Hiram Brook Member
Frederick Brook Member
Dawson Settlement Member
McQuade Brook Formation
Memramcook Formation (Late Devonian–Early Carboniferous)
PRE-LATE DEVONIAN
Crystalline basement
331
Well with NBDNR Unique Identification (UI) number; see Appendix 1
Fault with interpreted sense of movement
42 AT
Spore locality

Figure 14. Cross-section B–B' (on Plate 4) reaches from Well 254 north of Stoney Creek to Wilson Brook. The Stoney Creek Field lies in the Albert Formation between Wells 181 and 331. Section interpretation is supported by seismic reflection profiles. The southern part of the section in subsurface is highly speculative. The Salem Fault is omitted for the sake of clarity.

uppermost bed of red, greyish green, or grey polymictic conglomerate or coarse-grained lithic or feldspathic sandstone typical of the Memramcook Formation. This definition is more restrictive than that of Norman (1941b), Gussow (1953), Popper (1965), McLeod and Ruitenberg (1978), and Carter and Pickerill (1985a), all of whom placed the contact much higher in the section at the colour boundary where the mainly fine-grained red strata (the McQuade Brook Formation of this report) give way to grey rocks of the Albert Formation. The Memramcook–McQuade Brook contact as used herein is placed where the dominantly coarse-grained rocks of the Memramcook are replaced by the dominantly fine-grained sandstones and mudrocks of the McQuade Brook Formation.

Depositional Environment: The multiple-stacked, fining-upward cycles of conglomerate, sandstone, and minor mudrocks that characterize the Memramcook Formation in and near the type section and at Shediac River are interpreted to be mainly braided fluvial deposits. Rust (1978) and Miall (1978, 1985, 1992) point out that the main lithofacies of gravel-dominated rivers are massive, horizontally stratified conglomerate with minor trough and planar cross-bedded conglomerate and sandstone and subordinate mudstone intervals. The cobble- and boulder-dominated sequences at Shediac River, Irishtown, and near Sweet Mountain are interpreted as braided stream beds that likely were deposited in the proximal part of alluvial fans. The thick and massive, internally structureless, cobble and boulder conglomerate beds at Irishtown, Sweet Mountain, and against the Gaytons Fault in the Gayton quarry (Fig. 11) may be debris- or mass-flow deposits. If so, they suggest proximal alluvial fan deposition (Bull 1972; Rust 1978). The finer grained pebbly sandstone, trough and planar cross-bedded sandstones, and minor overbank mudrocks that characterize the upper part of the Memramcook type section are more distal fluvial sequences and are analogous to Miall's (1978, his Fig. 1) South Saskatchewan Type distal sandy braided river deposits. In summary, the lower part of the Memramcook Formation is dominated by coarse conglomerates and sandstones that probably were deposited largely in the proximal to medial parts of alluvial fans. The upper part of the formation represents more distal fluvial braided deposits.

The wide distribution of the fans and the contrasting composition of locally derived clasts at each locality imply that escarpments and active faults existed in each area. Thus, the deposits of the Memramcook Formation record an early history of active faulting along the margins of the juvenile basins. In each area, the clasts compare closely with the adjacent basement bedrock, indicating that the subsequent regional lateral displacement on the basin-bounding faults was fairly insignificant.

Age: The Memramcook Formation has been dated from 23 spore assemblages in the report area (Table 3). The assemblages are from the type section area at Stony Creek and from beds along and adjacent to Shediac River north of Irishtown (Fig. 10). McGregor (1962, 1970, 1983a, 1983b) reports Late Devonian (early to late Famennian) ages for eight spore assemblages at the type section. The formation also yields Famennian spores (St. Peter 2006a) from southwest of the Shediac River block in the subsurface of the Cocagne Subbasin. In contrast, Dolby (1991, 1995a, 2002, 2004, 2006a, 2007) cites earliest Carboniferous (early to middle Tournaisian Zones 1–2A) ages (Fig. 15) from 15 spore-bearing samples at Shediac River. These apparently younger ages could imply that the fault-bounded block of beds at Shediac River represents a stratigraphically higher part of the formation than was sampled at the type area.

Sub-system	Stage	Sub-stage	Miospore Zones			
EARLY CARBONIFEROUS	VISEAN	V3	*spinosa–magnificus*		SM	E
			acadiensis–triradiatus		AT	D C
		V1 to V2	*stephanephorus*		NS	B A
			pusilla–columbaris			
	TOURNAISIAN	Tn 3	*decorus–claviger*			5
			pretiosus			4
			vallatus	*cabotii*		3B
						3A
				distinctus–abstrusus		2B
						2A
		Tn 2				1D
						1C
			? *rotatus–explanatus* ?			1B
		Tn 1b				1A
LATE DEVONIAN	FAM-MENIAN		*lepidophyta–nitidus*			

Sources of Miospore Zones

Late Devonian	Martel et al. (1993)
Tournaisian	Utting et al. (1989); Utting (pers. comm., 1997)
Visean	Utting (1987); Utting and Giles (2004)
Tournaisian	Alphanumeric designations (e.g., Zone 1B), informal and unpublished: after Dolby (1996a)
Windsor Group	Macrofaunal subzones A to E of Nova Scotia: after Bell (1929)

Figure 15. Palynological zonation of the Late Devonian–Early Carboniferous (Famennian, Tournaisian, Visean) for New Brunswick and Nova Scotia, modified from Utting et al. (1989).

Table 3. Spore localities (reference codes) for assemblages in the Maritimes Basin in the report area of southeastern New Brunswick (see St. Peter and Johnson 2009 for full details).

Formation / Member	**Spore Localities (Reference Codes)**		**Map Plate(s)**
	Number Codes	***Alphanumeric Codes***	
Memramcook Formation	1 to 4	A to F	Plate 3
McQuade Brook Formation	5 to 25	G to N	Plates 3, 4, 5
Albert Formation	26 to 49, 75	P to AD	Plates 3, 4
Steeves Mills Formation	50, 51	AE, AF, AG	Plate 4
Indian Mountain Formation	52, 53	–	Plate 3
Round Hill Formation	54	AH, AJ, AK	Plate 4
Stilesville Formation	55 to 57	–	Plate 3
Gautreau Formation	58 to 78	AA, AL to AS	Plates 3, 4
Weldon Formation	79	AT	Plate 4
Briggs Cross Formation	80, 81	AU, AV	Plate 3
Ridge Brook Formation	–	–	–
Hillsborough Formation	–	–	–
Gays River Formation	–	–	–
Macumber Formation	82	–	Plate 4
Upperton Formation	–	–	–
Lime-kiln Brook Formation	83 to 85	AW, AX	Plates 4, 6
Maringouin Formation	86	–	Plate 6
Shepody Formation	87 to 105	AY	Plates 4, 5, 6
Enragé Formation	106	–	Plate 5
Hopewell Cape Formation	107, 108	–	Plates 3, 4
Boss Point Formation			
Chignecto Bay Member	109 to 111	–	Plates 5, 6
Ward Point Member	155 to 168	CA to CD	Plates 4, 5, 6
Breau Creek Member	112 to 135, 139	AZ to BC, BN	Plates 3 to 6
Cole Point Member	136 to 138, 140 to 154	BD to BL, BO to BZ	Plates 2 to 5
Grande Anse Formation	169	CE to CK	Plates 4, 5
Salisbury Formation	170 to 176	CM, CN, CP, CQ	Plates 2 to 5
Minto Formation	–	–	–
Richibucto Formation	177 to 185	CR to CW	Plates 2, 3
Tormentine Formation	–	–	–

The palynological data demonstrate that the Memramcook Formation in its lower parts straddles the Devonian–Carboniferous boundary, making it analogous to the Horton Bluff Formation in the Horton type section in the Windsor Subbasin of Nova Scotia (Martel et al. 1993). Martel et al. (1993) give additional sites of Late Devonian (Famennian) strata at the base of the Horton Group in Nova Scotia.

Relationship to Previous Stratigraphy: The Memramcook Formation in its type section as described herein is restricted to the basal coarse facies of the Memramcook Formation of Norman (1941b), Gussow (1953), Popper (1965), Carr (1968), and McLeod and Ruitenberg (1978). The overlying fine-grained beds, which these authors assigned to the Memramcook Formation, are placed herein in the McQuade Brook Formation (see ***McQuade Brook Formation,*** below). Similarly, fine-grained redbeds and grey beds in fault blocks in the Indian Mountain Deformed Zone at O'Neil and McQuade Brook northwest of Irishtown (Fig. 10) and in the Sweet Mountain area (Plate 4) are removed herein from the Memramcook Formation of Norman (1941a, 1941b), Gussow (1953), Popper (1965), and Carr (1968) and assigned instead to the McQuade Brook Formation. The coarse Memramcook redbeds along Shediac River were previously included in the Moncton Group (name now abandoned) by Norman (1941b). Popper (1965) was uncertain whether the coarse redbeds at Shediac River were

Memramcook or possibly a younger unit. Carr (1968) assigned those same strata at Shediac River to an unnamed boulder conglomerate unit but apparently was unsure of the unit's stratigraphic position. He mapped it as being in part equivalent to the Memramcook Formation, Albert Formation, and Moncton Group.

McQuade Brook Formation

Author: St. Peter (2006a).

Type Section: The outcrops of mainly fine-grained redbeds along McQuade Brook just east of McQuade, Westmorland County (NTS 21 I/02; Plate 3), are the most continuous exposures of the formation and are designated as the type section by St. Peter (2006a).

Definition and Description: The McQuade Brook Formation comprises a sequence of earliest Tournaisian, fine-grained red and grey, fluvial strata that gradationally overlie the Memramcook Formation and gradationally underlie the predominantly lacustrine Albert Formation.

St. Peter (2006a) and Park and St. Peter (2009) describe the McQuade Brook Formation in the Indian Mountain Deformed Zone. At the McQuade type section and in the belt between the Smith Creek and O'Neil faults, the formation comprises interbedded reddish brown or grey mudstone and siltstone and reddish brown or grey, very fine-grained to fine-grained, parallel- and ripple-laminated sandstone (Fig. 16). Minor grey to reddish grey, medium- to coarse-grained, flat- or cross-bedded sandstone occurs locally. The beds are typically arranged into fining-upward units. The rocks along Shediac River on the north side of the North River Fault are similar but contain thick zones of tectonic breccia of sandstone, siltstone, mudstone, and shale. Grey to reddish grey granular sandstone and small pebble conglomerate with intraclasts of mudstone and micritic limestone are locally present.

Small outcrops of McQuade Formation occur in the easternmost Moncton Subbasin along streams on the west side of Memramcook River. The formation there comprises grey to maroon mudstone, subfissile shale, and siltstone with lesser beds of grey to reddish brown, very fine-grained to medium-grained sandstone. The sandstone beds display parallel and ripple laminations. Current ripples, climbing current ripples, and rarely chevron-shaped, wave-formed ripples are mapped locally. Beds of coarser grained feldspathic sandstone have been noted, and plant detritus is common in the grey siltstone and finer sand beds.

The lithotypes in the stream outcrops at Memramcook are mirrored in the thick succession of red and grey mudstones and rare thin intervals of siltstone and laminated and rippled sandstone in Well 709 located on the TCH about 5.5 km east-southeast of Memramcook. Evidence from the vertically drilled borehole indicates that red mudstone dominates the upper part of the formation, and that grey mudstone is more abundant in the lower part. The transitional red–grey coloration boundaries are commonly marked by rooted zones. Rare intervals of intraformational breccia up to 3 m thick are cited in the company litholog for that hole. McQuade Brook rocks at Upper Dorchester, north of Ferndale, and north of Sweet Mountain (Plate 4) consist of grey to maroon mudstone, siltstone, and fine-grained sandstone.

Distribution and Thickness: In addition to being exposed at the type section in the Indian Mountain Deformed Zone, the McQuade Brook Formation underlies a tract in the IMDZ

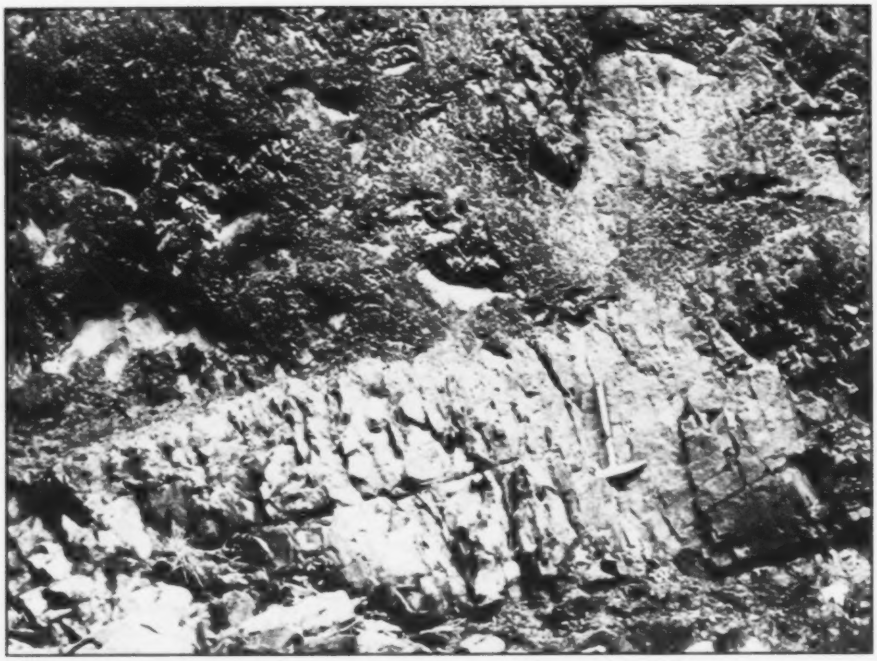


Figure 16. Thick bed of grey, fine-grained sandstone overlain by a thick interval of reddish brown mudstone of the McQuade Formation at its type section along McQuade Brook.

between the Smith Creek and O'Neil faults from Catamount to McQuade Brook (Fig. 10). In the eastern Moncton Subbasin (Fig. 6), the formation is exposed along streams on the west side of Memramcook River near Memramcook and farther south on the east side of the river at Upper Dorchester (Plate 4). In the westernmost part of Plate 4, McQuade Brook rocks overlie a condensed section of Memramcook Formation north of Ferndale and are exposed in a fault-bounded tract on the northwestern side of Sweet Mountain.

In the subsurface, the McQuade Brook Formation is known from boreholes in the Cocagne Subbasin (St. Peter 2006a) and was penetrated in the Moncton Subbasin below the Albert Formation in several wells on the south flank of the Westmorland Uplift from Well 709 in the east (Plate 5) to Well 334 near the community of Little River in the west (Fig. 13; Plate 4). The McQuade Brook Formation is apparently absent at surface around Rosevale on the north side of the Caledonia Fault. However, the formation was intersected at a depth of 631.1 m in Well 200 in that area. In the Sackville Subbasin, the sole evidence of the McQuade Brook Formation is from Well 716 just northeast of Woodhurst. The well cut fine-grained redbeds of the formation in depth interval 2538 m to 3165 m (sub-Kelly).

The thickness of the McQuade Brook Formation in the type section is unknown. The contacts with the Albert Formation there are almost certainly defined in all places by faults, as evidenced by contrasting bedding orientations in outcrops adjacent to the contacts and by sheared and fractured rocks in the contact zones. The section along McQuade Brook shows several dip reversals. The discontinuous nature of exposures prevents determining whether the changes in dip result from fold closures or juxtaposed fault blocks (Park and St. Peter 2009). In the tract between the Smith Creek and O'Neil faults at O'Neil and from there southwest to Shaw Brook (Fig. 10), McQuade Brook beds dip quite uniformly to the east and, if not broken by faults, imply that the formation is at least 1 km thick.

In the Memramcook area, the variety of bedding attitudes in exposures along streams on the west side of Memramcook River (Plates 3, 4) prevents an estimate of formation thickness from surface data. However, at the nearby Well 404 at Little Dover, an incomplete section of the McQuade Brook Formation has a thickness of about 600 m (NBDNR 2004). From the Memramcook area west to Well 405 at Scotts Hill and from there southwestward to Well 254 just northeast of Baltimore Station, the McQuade Brook Formation thins dramatically. It is absent above the Memramcook Formation in the latter well (Fig. 14). On the south side of the Moncton Subbasin in Well 200 at Rosevale, the formation is only 19.5 m thick. East of Memramcook at Well 709, the formation was intersected from 142 m to total depth at 1650 m. Core-to-bedding angles of about 55° suggest a minimum thickness of 865 m in that area, assuming the formation is not repeated or otherwise disturbed by faults. About 4 km farther south in the Sackville Subbasin, the drill thickness of the section cut in the vertically drilled Well 716 is 627 m. There, the bedding dip in the formation is estimated at about 45° from a tadpole plot of bedding from a formation-imaging log. A true thickness of approximately 440 m is therefore indicated.

Lower and Upper Boundaries: The lower boundary of the McQuade Brook Formation with the Memramcook Formation is assumed to be conformable and in most areas gradational. It is represented by a zone of coarse-grained facies of the Memramcook Formation interbedded with finer grained sandstones, siltstones, and mudstones of the McQuade Brook Formation. Rock types in the scattered outcrops in the Memramcook area support this assumption and have been so interpreted by Norman (1941b), Gussow (1953), Popper (1965), and McLeod and Ruitenberg (1978). The gradational nature of the contact is also supported by the litholog of Well 716. The top of the uppermost conglomerate in that well sits at a depth of 3165 m and is designated as the contact between the Memramcook and McQuade Brook formations, above which the McQuade Brook section becomes finer. For example, from the base at 3165 m to 3069 m, the formation comprises about 20% sandstone intervals that gradually decrease upward in thickness and number. Sandstone intervals are rare above 3069 m.

Well 334, situated about 3.5 km east of the community of Little River, also provides evidence for the nature of the Memramcook–McQuade Brook boundary. The McQuade Brook Formation in the well lies between 1305 m and total depth at 1615 m. The upper part of the formation is reddish brown mudstone and minor grey mudstone, whereas the lower 110 m comprises about 50% fine-grained sandstone intervals, indicating that the formation becomes coarser at depth. The lower sandy section is interpreted as the transitional interval with the underlying Memramcook Formation, which was not reached in the well. The coarse-to-fine gradational nature of the boundary between the formations is also demonstrated 13 km south of Well 334 in outcrops of the Memramcook Formation along East Branch Little River and in small, nearby exposures of Memramcook and McQuade Brook along the road north of the river. In Well 200 at Rosevale, a sharp boundary at 650.6 m shows red mudstone lying on red and green conglomerate and grits of the Memramcook Formation. The litholog of cuttings for Well 200 reports limestone bands in the basal 3 m of the McQuade Brook Formation. The limestone is interpreted as pedogenic carbonate within the red mudstone.

The upper boundary of the McQuade Brook Formation with the Albert Formation is also interpreted to be depositionally gradational and apparently diachronous (see ***Lateral Facies Relationships*** and ***Age,*** below). The McQuade Brook–Albert boundary was intersected in several wells in and near the Stoney Creek Field, among them being Wells 317, 331, and 332 (Fig. 13, 14). Cuttings obtained from those wells show that the characteristically interbedded grey sandstones and shales of the Albert Formation change over a few metres or tens of metres to grey and reddish brown sandstones and red mudstones of the McQuade Brook Formation. Previous workers (Norman 1941a, 1941b; Gussow 1953; Popper 1965; McLeod and Ruitenberg 1978) included the strata assigned herein to the McQuade Brook Formation in the fine-grained upper part of their Memramcook Formation. They noted the contact as gradational and placed it where the dominant red of their Memramcook Formation gives way to the dominant grey of the Albert Formation (Gussow 1953, p. 1730).

St. Peter (1992) attempted to differentiate the Albert Formation from the underlying rocks on the basis of not just colour change but also (and more importantly) lithological criteria. He noted that features characterizing the Albert Formation include sandstone beds that provide conclusive evidence of wave-generated ripples, shale or mudstone beds with kerogenous algal laminae (lamalginites), and beds with fish skeletons, fish detritus, ostracods, algal oncolites, or algal stromatolites. However, in applying those criteria to the Albert Formation, some of the beds assigned herein to the McQuade Brook Formation (e.g., rare sandstone beds bearing wave-shaped ripples in the dominantly red mudstone sequence just west of Memramcook River) were included in the Albert Formation by St. Peter (1992).

It subsequently proved more reliable to assign such rocks and their stratigraphic equivalents to the Albert Formation on the basis of several features and not just a single criterion such as wave ripples. The overall aspect of those rocks and the recognition of a widely distributed and identifiable fine-grained 'redbed' sequence below the 'grey Albert' and above the 'coarse Memramcook' are the main justifications for establishing the McQuade Brook as a separate formation and for placing the fine-grained clastics west of Memramcook River within it.

Lateral Facies Relationships: The palynological data for the Memramcook, McQuade Brook, and Albert formations (see St. Peter and Johnson 2009) provide strong evidence that both the lower and upper boundaries of the McQuade Brook are diachronous. The Memramcook and McQuade Brook formations are in part proximal and distal temporal equivalents. Similarly, it seems likely that the mud-dominated upper part of the McQuade Brook Formation is laterally equivalent to the lower fluvial and lacustrine beds of the Albert Formation.

The palynological evidence is supported by lithologs for wells drilled between Berryton and Baltimore Station and between Memramcook and Scotts Hill. The thickness of the McQuade Brook Formation inferred from well data and from the McQuade exposures in the Memramcook area indicates that the formation thins from Berryton to Baltimore Station and from Memramcook to Scotts Hill. In fact, by Well 254 (Fig. 14), the formation apparently has thinned to a zero edge. In that well, coarse red conglomerates of the Memramcook Formation lie on crystalline basement and are overlain by a much thinned Albert Formation of grey sandstone and kerogenous mudstone. Thus, the thickness data and the relationship of the McQuade Brook Formation to its bounding rocks between Berryton and Memramcook strongly suggest that the McQuade Brook is in part laterally equivalent to the upper part of the Memramcook Formation and the lower part of the Albert Formation.

Park and St. Peter (2009) provide lithological evidence of the McQuade Brook and Albert formations being in part facies equivalents. In the eastern fault-bounded block of Albert Formation at McQuade Brook, typical dark grey to brown kerogenous shales, mudstones, and associated grey sandstones of the Albert Formation contain intervals of reddish brown mudstone and fine-grained sandstone, the latter being more characteristically associated with the McQuade Brook Formation. On the basis of the interstratification of 'grey beds' associated with the Albert Formation and 'redbeds' associated with the McQuade Brook Formation, Park and St. Peter (2009) conclude that this area shows upland alluvial–fluvial deposits of the McQuade Brook Formation interfingering with lacustrine deposits of the Albert Formation.

Depositional Environment: The McQuade Brook Formation (upper Memramcook Formation of previous workers) is interpreted as largely fluvial (alluvial) deposits. Popper (1965) suggests that the fine-grained rocks of the McQuade Brook Formation represent a basinal, playa-like sequence that is in part equivalent to the more proximal basin-edge deposits of the coarser Memramcook Formation. Nothing in the present investigation refutes that interpretation. Fining-upward cycles of sandstone, siltstone, and mudstone are interpreted herein as fluvial deposits (e.g., see Miall 1992).

The formation's general paucity of sand, its fine grain size, and the limited interval thickness of the sand part of the cycles all imply deposition distal to a source area. The grey (but not postdepositionally reduced) shale and mudstone intervals imply deposition under constantly wet, anoxic conditions, perhaps in standing water. Similarly, the rare wave-formed ripples in some sand beds could suggest deposition in ephemeral ponds. The presence of ephemeral ponds on the lower or distal part of an alluvial plain could be reasonably expected and in fact would 'foreshadow' the perennial lake(s) that existed during deposition of the ensuing Albert Formation.

Age: Forty-one palynological assemblages from surface and well samples have been investigated for the McQuade Brook Formation in the report area (Table 3). The dataset collectively indicates that the McQuade Brook Formation is earliest Carboniferous, specifically earliest Tournaisian Zone 1A to middle Tournaisian Zone 2A (Fig. 9, 15). The assemblage data tentatively suggest that beds in the Indian Mountain Deformed Zone (IMDZ) may be slightly younger than those in the eastern Moncton Subbasin.

The better dates for the IMDZ samples typically yield an age of Tournaisian Zones 1C–2A, whereas dates from the well and surface samples in the Moncton Subbasin suggest an age of Tournaisian Zone 1A–1B. The Moncton Subbasin samples were obtained from Well 709 just east of Memramcook to Well 334 near the community of Little River. Also, two samples at depths of 2866 m and 2877 m from Well 716 near Woodhurst give an age of Tournaisian Zone 2A (Dolby 2001a), suggesting that the McQuade Brook Formation in the Sackville Subbasin may be slightly younger than in the adjacent Moncton Subbasin.

Relationship to Previous Stratigraphy: The McQuade Brook Formation is equivalent to the upper fine-grained lithofacies (or informal upper member) of the Memramcook Formation as defined by Norman (1941a, 1941b), Gussow (1953), Popper (1965), Carr (1968), McLeod and Ruitenberg (1978), and McLeod (1980), and to the basal part of the Albert Formation of St. Peter (1992, 1993).

Albert Formation

Authors: Dawson (1853); Bailey and Ells (1878); revised by Ami (1900), Wright (1922), Norman (1932,1941a), Greiner (1962; introduced three formal members), St. Peter (1992), and herein.

Type Section: A single type section has never been designated for the Albert Formation. An accessible although highly faulted section of the formation is located near Boudreau Village on the eastern shore of Petitcodiac River, Westmorland County (NTS 21 H/15; Plate 4) and is described in detail by Park and St. Peter (2005). Greiner (1962) assigned separate type sections for each of his three members, those being (from base to top) the Dawson Settlement, Frederick Brook, and Hiram Brook members. He designated type sections for the Dawson Settlement and Hiram Brook members in the subsurface in Wells 305 and 243, respectively. He defined the type section for the Frederick Brook Member as the outcrops of organic-rich mudrocks along Frederick Brook west of Albert Mines (Plate 4). Pickerill et al. (1985), Carter and Pickerill (1985b), and St. Peter (1992) show that Greiner's (1962) type sections give an incomplete representation of the lithological, lateral, and vertical variability of the Albert Formation. Moreover, cuttings from the wells for the Dawson Settlement and Hiram Brook members offer continuous sections but provide no information about bedforms and incomplete information about contact relationships. (See descriptions of members, later.)

Definition and Description: The Albert Formation as applied in this report describes a middle sequence in the Horton Group of mainly grey fluvial and lacustrine strata of early Tournaisian age that gradationally succeeds fine-grained redbeds of the McQuade Brook Formation and is conformably overlain by green and red fluvial clastics of the Indian Mountain Formation or is laterally gradational with and overlain by coarse-grained redbeds of the Steeves Mills Formation. Norman (1932) was the first to use the name 'Albert formation' in nearly the same sense as presently employed, which is as the grey beds lying above the red and grey McQuade Brook Formation and lying below either 1) grey shales and evaporites of the Gautreau Formation, or 2) redbeds of one of several formations (Fig. 9). Norman subsequently (1941a) changed his interpretation of what beds should be assigned to the Albert and included the younger Gautreau evaporites in his 1941 definition. Greiner (1962) followed Norman (1932) in excluding the Gautreau evaporites and coeval mudrocks from his Albert Formation. Greiner later (1974) produced a panel diagram to indicate the subsurface distribution of his three members in southeastern New Brunswick but did not draft a map showing his interpretation of their surface distribution. The current report redefines the Albert Formation in keeping with Norman (1932). Accordingly, it excludes the overlying mudstones and evaporites of the Gautreau Formation, which instead are assigned herein to the newly named Sussex Group (see ***Gautreau Formation***, later). Greiner's (1962) three members (Dawson Settlement, Frederick Brook, and Hiram Brook) are retained.

The Dawson Settlement and Hiram Brook members of Greiner (1962) are mainly sandstone, siltstone, shale (including minor kerogenous shale), and lesser conglomerate, whereas the medial Frederick Brook Member comprises significant kerogenous shale (oil shale) and kerogenous mudstone. Greiner (1962, 1974) produced a regional map showing the distribution of lithofacies in the Albert Formation. Pickerill et al. (1985) and Carter and Pickerill (1985b) expanded the number of identifiable lithofacies and ascribed a plausible environment of deposition to each. St. Peter (1989b, 1992) further refined those lithofacies and attempted to map their lateral and vertical distribution in the eastern part of the Moncton Subbasin.

However, subsequent workers (St. Peter 2002; Park and St. Peter 2005; Hinds and St. Peter 2006; St. Peter 2006a; Park et al. 2007) demonstrated that the member distribution as regionally portrayed by Greiner (1974) and the lithofacies as mapped by St. Peter (1992) are either incorrect or at best crude approximations in many areas. On the basis of this recent work, significant rock bodies mapped by Greiner (1974) and St. Peter (1992) as Albert Formation are now assigned to either the McQuade Brook Formation or the Sussex Group, particularly the Round Hill and Gautreau formations.

The Albert Formation was described in various levels of detail by Wright (1922), Norman (1941a, 1941b), Gussow (1953), Greiner (1962, 1974), Pickerill and Carter (1980), St. Peter (1982, 1989b, 1992, 1993), Carter (1985), Carter and Pickerill (1985b), Pickerill et al. (1985), and Smith (1985). However, in the report area, a formal attempt has not yet been made to map in detail the surface and subsurface distribution of the formation's three members. Consequently, the Albert Formation is shown as undivided on Plates 3 and 4. Although the following accounts of the distribution of the members are guided by the lithofacies distributions on the 1:20 000-scale maps of St. Peter (1989b) and by regional borehole records, it is important to appreciate that much stratigraphic and structural work remains to be done to fully define the local and regional placement of contacts between the members.

Distribution and Thickness: The Albert Formation in the report area is exposed in parts of the Moncton Subbasin, Indian Mountain Deformed Zone, and Sackville Subbasin (Fig. 6, 9, 10). In the southeastern part of the Moncton Subbasin along the Caledonia Uplift (Fig. 6), Albert beds are recognized near Parkindale, Prosser Brook, Rosevale, and Albert Mines. Farther east, the formation crops out along Petitcodiac and Memramcook rivers and along streams entering those rivers near Dover, Memramcook, Boudreau Village, and Upper Dorchester. In the Indian Mountain Deformed Zone, the Albert Formation is exposed from Pacific Junction northeastward to McQuade Brook (Fig. 10). In the Sackville Subbasin, the only known exposure of the formation is on the south side of the Dorchester Fault at Upper Dorchester (Fig. 3, 6). The Albert Formation is regionally present in the subsurface of the Moncton Subbasin (Fig. 13, 14), as evidenced by data from oil and gas wells (Foley 1989; St. Peter 1992; Nickerson 1994). Well data also indicate that Albert beds may exist at depth in the Cocagne Subbasin (St. Peter 2006a).

No complete surface section of the Albert Formation exists in any one location from which a thickness determination can be made. The exposed sections represent only limited parts of the formation. As well, many surface sections are partly eroded by unconformities, cut by faults, or characterized by other structural complications that hamper thickness estimates. A nearly complete Albert section was intersected in Wells 331 and 332 that lie along the southern part of the Stoney Creek Field. In both wells, drilling was discontinued in red mudstones and interbedded fine-grained sandstones of the McQuade Brook Formation (Fig. 13). The drill thickness of the Albert Formation in Well 331 is 1202 m and in Well 332 is 1025 m. Assuming a dip of 20°, the true thickness of the formation is about 1130 m in the former well and 960 m in the latter. The Albert section in Well 333 (5 km southwest of Hillsborough) lies in depth interval 1680 m to 3013 m, giving a drill thickness of 1333 m. Drilling in this well was discontinued while still in the Albert Formation (Fig. 14). A seismic reflection line that crossed Well 333 shows a shallow dip for the Albert, indicating the formation's true thickness there may exceed 1300 m. The thickness of the formation in the IMDZ between Pacific Junction and McQuade Brook (Fig. 10) may be up to 1400 m. This assumes that the formation has an average dip of approximately 60°SE and that the succession is not thickened by compressional faults or folds or thinned by extensional faults. Park and St. Peter (2009) offer additional cautions with respect to this thickness estimate.

Relationship to Previous Stratigraphy: The bituminous shales of the Albert Formation in Albert County were first described by Gesner (1841). The name 'Albert Formation' evolved historically from Dawson (1853) and Bailey and Ells (1878), who used the term 'Albert shales'; to Ami (1900), who used both 'Albert shales' and 'Albert formation'; to Wright (1922) who used 'Albert Series.' Norman (1932) used 'Albert formation' and later (1941a) established the present usage as 'Albert Formation.' Wright (1922) subdivided his Albert Series into three informal zones on the basis of beds exposed in the Dover, Albert Mines (Frederick Brook), and Rosevale areas (Plate 4). Gussow (1953) used Norman's 1941 definition and mapped the Albert Formation as all the grey strata that lie below the Windsor Group in the Moncton Subbasin, Cocagne Subbasin, and Indian Mountain Deformed Zone. Greiner (1962) subsequently used Wright's zonal stratigraphy and applied formal member names to each zone, those being (from base to top) the Dawson Settlement, Frederick Brook, and Hiram Brook members.

Dawson Settlement Member (Albert Formation)

Author: Greiner (1962).

Type Section: The type section for the Dawson Settlement Member was designated by Greiner (1962, p. 228) as depth interval 4000 ft to 5193 ft (1219–1583 m) in Well 305 near Dawson Settlement. The current authors have retained the type section in Well 305 but have modified the upper and lower interval boundaries. Greiner (1962, p. 230) described the Frederick Brook Member as comprising organic shales, minor siltstone, and rare sandstone; he cited the contacts with the underlying Dawson Settlement Member and overlying Hiram Brook Member as gradational and placed "where sandstone and siltstone predominate." The company litholog of Well 305 shows several sandstone intervals interbedded with shale intervals for 200 ft (60 m) above Greiner's upper boundary of the Dawson Settlement Member at 4000 ft (1219 m). The boundary between the organic-bearing shale unit (Frederick Brook Member) and the interbedded sandstone and shale unit (Dawson Settlement Member) in the current report is placed at a depth of 3801 ft (1159 m) at the top of a 5 ft (1.5 m) thick conglomerate bed (Table 4). The company litholog notes the top of the first redbeds (McQuade Brook Formation) at 5115 ft (1559 m), not 5193 ft (1583 m) as Greiner indicated. In summary, the type section of the Dawson Settlement Member is modified herein from that of Greiner and redefined as depth interval 3801 ft to 5115 ft (1159–1559 m) in Well 305 just north of Dawson Settlement, Albert County (NTS 21 H/15; Plate 4).

Definition and Description: The Dawson Settlement Member is the basal member of the Albert Formation. It gradationally overlies the McQuade Brook Formation and is gradationally overlain by the Frederick Brook Member (Albert Formation). It comprises an early Tournaisian sequence of mainly grey fluvial and lacustrine sandstone, siltstone, and shale; subordinate tongues of deeper lacustrine organic siltstone and shale; subordinate upland alluvial conglomerate; and rare shallow lacustrine (beach) limestones.

The type section of the Dawson Settlement Member in Well 305 occurs in the Moncton Subbasin at Dawson Settlement. The section exemplifies the member's range of finer grained clastics and the scale of interbedding of rock types. The description of the type section in Greiner (1962) has some deficiencies; accordingly, a summary of the company litholog is provided below (Table 4). The original log gives the lithological interval depths in feet, which are retained for simplicity. The sandstones (Table 4) are typically light to medium grey and slightly calcareous, the shales are typically dark grey to nearly black and slightly calcareous, and the kerogenous shales are more typically brownish grey and dolomitic.

The Albert Formation is exposed in the Moncton Subbasin around Rosevale in a belt along the north side of the Caledonia Fault, about 15 km southwest of the type section. Previous workers (Greiner 1962; St. Peter 1989a, 1989b, 1992) did not attempt to differentiate the Dawson Settlement, Frederick Brook, or Hiram Brook members in this area. Greiner (1974, his Fig. 3) recognized rocks of the members in Well 200 at Rosevale but made no effort to show their relative surface distribution. The company litholog for the well demonstrates that the Dawson Settlement Member comprises mainly grey shale, lesser dolomitic kerogenous shale, kerogenous mudstone, and fine- to medium-grained, micaceous sandstone. The sandstone intervals are up to 9 m thick, and some show fining upward from coarse at the base to fine at the top.

Table 4. Summary description of type section for the Dawson Settlement Member, Albert Formation, in Well 305.

Depth (ft)	**Depth (ft)**	**Thick-ness**	**Description** Well location: 45°57'28"N, 64°45'43.8"W at a ground elevation of 140.7 m
–	3801	–	**Frederick Brook Member:** shale and kerogenous shale
3801	5115	1314	**Dawson Settlement Member**
3801	3806	5	Conglomerate: grey, quartzose
3806	3851	45	Sandstone: medium grained; minor shale
3851	3910	59	Shale to kerogenous shale
3910	3954	44	Sandstone, shale, and kerogenous shale in intervals 5–10 ft thick
3954	3994	40	Shale and sandy shale
3994	4026	32	Sandstone: coarse grained
4026	4071	45	Shale and sandy shale
4071	4193	122	Sandstone (fine to coarse grained) and shale in intervals 5–20 ft thick
4193	4245	52	Shale and sandy shale
4245	4261	16	Sandstone: coarse grained, quartzose
4261	4435	174	Shale and sandy shale; rare sandstone intervals
4435	4526	91	Sandstone: coarse grained
4526	4555	29	Shale and sandy shale
4555	4638	83	Sandstone: minor shale at 4587–4600 ft
4638	4741	103	Sandstone (fine to coarse grained) and shale in intervals 5–20 ft thick; shale is in part kerogenous and is reddish brown at 4638–4655 ft
4741	4768	27	Shale and sandy shale, in part kerogenous
4768	4824	56	Sandstone, purplish limestone, shale, and rare kerogenous shale
4824	5089	265	Shale and rare kerogenous shale
5089	5115	26	Shale and sandy shale with slight green tint
			McQuade Brook Formation
5115	5193 (total depth)	78	Shale and sandy shale, reddish brown and grey with percentage of red increasing with depth

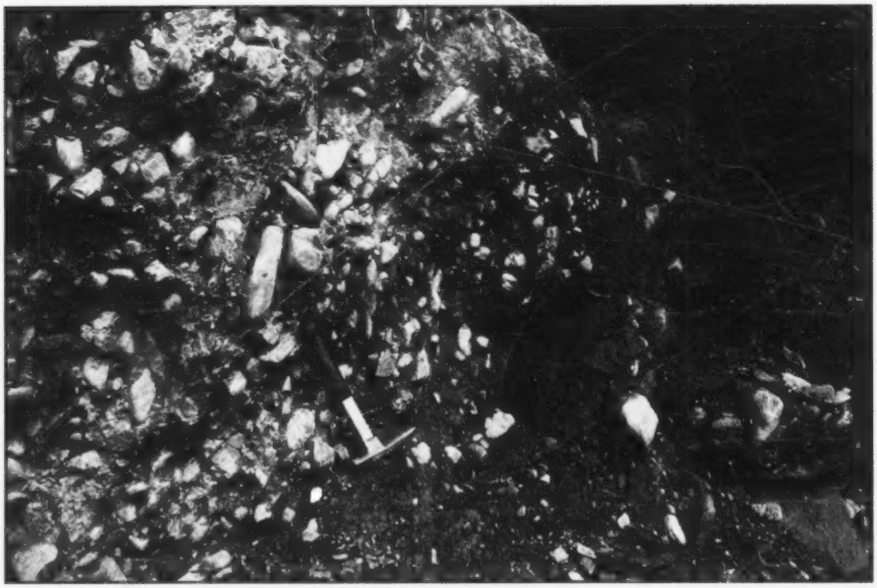


Figure 17. Thick, massive beds of greyish green, polymictic conglomerate interbedded with dark grey sandstone of the Dawson Settlement Member, Albert Formation, along Prosser Brook Road about 3 km west of Rosevale.

West of Rosevale, Park et al. (2007, their Fig. 5a) assign to the Dawson Settlement Member a sequence of mainly coarse-grained beds exposed along tributaries of Prosser Brook on the north side of the Caledonia Fault and unconformably below the Hillsborough Formation. The outcrops along the tributaries are small but reveal thick, massive beds of greyish green, polymictic, granular to pebble conglomerate; thinner beds of similar conglomerate interbedded with grey to greyish green, medium-grained to granular and pebbly lithic sandstone; and greyish green siltstone and mudstone (Fig. 17). Clasts in the conglomerates are dominated by volcanic detritus comparable with crystalline rocks in the adjacent Caledonia basement. Some exposures consist only of thick units of mudstone. Rare intervals of brown, subfissile, kerogenous shale and brown-weathering, grey, calcareous, micaceous, medium- to coarse-grained sandstone provide convincing lithological evidence that they and their associated coarser interbeds are assignable to the Albert Formation.

As the Prosser Brook beds have not been dated palynologically, the preponderance of coarse-grained strata is the main reason for assigning them to the Dawson Settlement Member (Park et al. 2007). The stratigraphic relationship of those coarse strata to the three recognized members of the Albert Formation, which lie to the east near Rosevale, is unclear. The coarse beds have not been recently studied, and it is conceded they may lie above the Frederick Brook sequence and accordingly be equivalent to the Hiram Brook Member. For now, they are included under the Dawson Settlement Member.

In the western extremity of the report area around and just southwest of Parkindale (Plate 4), the Dawson Settlement Member contains significantly more coarse-grained rocks (Park et al. 2007). Southwestward from Pleasant Vale along Highway 895, small outcrops of the member on the roadside and in streambeds reveal an interlayered sequence of grey polymictic conglomerate, lithic to feldspathic sandstone, and lesser grey siltstone, shale, and locally kerogenous shale. At Pleasant Vale (Fig. 6) and farther northeast at Parkindale, the coarse conglomerate and sandstone sequence contains a 25 m thick limestone interval. The limestone beds in that interval comprise 1) grainstone carrying varied quantities of siliciclastic pebbles, granules, and sand as well as carbonate pellets and algal oncolites, 2) parallel-laminated quartzose and pelloidal packstone–grainstone, and 3) massive crystalline limestone. St. Peter (1992, p. 36–37) provides additional details about the limestones.

Coarse-grained strata in the lower part of the Albert Formation also occur in the easternmost Moncton Subbasin. In Well 708 at Edgetts Landing on the west shore of Petitcodiac River (Plate 4), the section between 1857 m and 2050 m comprises grey conglomerates and lithic sandstones and lies below organic-bearing mudstones interpreted as Frederick Brook Member. A similar coarse, polymictic, pebble to cobble conglomerate with interbeds of lithic sandstone and rare dark grey mudstone occurs in nearby Well 706. The Albert section in that well appears in depth interval 894 m to 1043 m. It rests unconformably on tectonized mafic volcanic rocks and is overlain by grey and red polymictic conglomerates, grits, sandstones, and mudstones interpreted as Round Hill Formation.

To the north in the Moncton Subbasin, along the east bank of Petitcodiac River at Dover, scattered outcrops of sandstone project through the tidal mudflats (Plate 4) and are tentatively assigned herein to the Dawson Settlement Member. The sandstone beds are typically grey, fine- to medium-grained, calcareous, micaceous quartzose arenites. They display ripples, climbing ripples, and rarely convolute laminations. They also feature fractures filled with calcite, rare small veins of solid black bitumen (albertite), and abundant dead oil stains. The beds are openly folded, but the bedding attitude in the isolated and largely mud-covered exposures suggests they are overlain by adjacently exposed interbedded kerogenous shale and siltstone, interpreted to represent basal beds of the Frederick Brook Member (St. Peter 1989b, his Plate 89-104A).

On the uppermost tributaries of Downing Creek near Dover, small outcrops show beds that are apparently at the stratigraphic level of the Dawson Settlement Member. The rocks include grey calcareous mudstone, massive to parallel-laminated siltstone, and interbeds of calcareous fine-grained sandstone. They are consistent with Dawson Settlement strata in well logs from the Stoney Creek Field. Layers of brown, fissile, kerogenous shale and black, micaceous sandstone occur on the northeasternmost tributary of the creek (McLeod 1980, his Plate 80-78A).

Distribution and Thickness: The lithological contents of the Dawson Settlement and Hiram Brook members are so similar that, in the absence of lithostratigraphic and structural knowledge, confident assignment to the Dawson Settlement versus the Hiram Brook is tenuous. Thus, determining the distribution of the three members of the Albert Formation must rely heavily on identifying the medial Frederick Brook Member and its contacts with the underlying Dawson Settlement and overlying Hiram Brook members. One complication is that Greiner's (1962) definitions of the allowable lithotypes and volumes in the Frederick Brook Member are very general, making it difficult to place the boundaries with the Dawson Settlement and Hiram Brook members, particularly where exposure is limited. Unresolved structural problems in many areas also complicate the issue of assigning the correct distribution and thickness to each member.

The type section of the Dawson Settlement Member in Well 305 (3801–5115 ft or 1159–1559 m) demonstrates that the member lies gradationally above the McQuade Brook Formation and below the Frederick Brook Member. Lateral to the type section, grey sandstones, siltstones, and intervening shales of the Dawson Settlement Member have been mapped with some confidence in the subsurface in and near the Stoney Creek Field (Fig. 13, 14; also see Greiner 1974, his Fig. 5; and Foley 1989, his maps and sections). Sandstone beds tentatively assigned to the Dawson Settlement Member crop out on the tidal flats at Dover on the east side of Petitcodiac River. Beds on the uppermost part of Downing Creek are presumably Dawson Settlement, given that kerogenous-bearing mudstones and shales assignable to the Frederick Brook Member lie further upsection to the south (Smith 1985; St. Peter 1989b, his Plate 89-104A). Dawson Settlement beds are also exposed in four additional areas of Plate 4: 1) just north of Upper Dorchester along the south tributary of Breau Creek, where they lie immediately above (west of) the McQuade Brook Formation (St. Peter 1989b, his Plate 89-104A), 2) north of the Gordon Falls Fault near Parkindale (Park et al. 2007), 3) beneath the Frederick Brook Member in the belt along the Caledonia Fault at Rosevale, and 4) possibly along tributaries of Prosser Brook west of Rosevale.

The drill thickness of the Dawson Settlement Member at its type section near Dawson Settlement is 400.5 m. The Albert Formation in that area dips at approximately 20°, indicating a true thickness for the member of about 375 m. The member seems to be somewhat thinner south of the type section in the Stoney Creek area (Fig. 13, 14). In Well 200 at Rosevale, the Dawson Settlement Member was intersected between the overlying Frederick Brook Member and the underlying McQuade Brook Formation, with an estimated drill thickness of 309 m. Beds in outcrops immediately south of the well indicate that the section dips at about 25°, suggesting a true thickness of approximately 280 m in that area. Park et al. (2007) cite a minimum thickness of 400 m for the Dawson Settlement adjacent to the Gordon Falls Fault southwest of Parkindale. East of Petitcodiac River, near the mouth of Breau Creek north of Upper Dorchester, the distribution of the McQuade Brook Formation and kerogenous mudrocks of the Frederick Brook Member indicate that the intervening Dawson Settlement Member is about 400 m thick (St. Peter 1989b, his Plate 89-104A).

Lower and Upper Boundaries: Numerous well records from the Stoney Creek Field and elsewhere in the eastern Moncton Subbasin, and discontinuous exposures across the member boundary at Breau Creek, provide evidence that the lower boundary of the Dawson Settlement Member is conformable and gradational with the underlying McQuade Brook Formation (see Gussow 1953; Greiner 1962; St. Peter 1992). In Well 200, grey shale of the Dawson Settlement Member sharply overlies reddish brown mudrocks of the McQuade Brook Formation at a depth of 631 m. Shallow boreholes drilled near Rosevale in 1942 by the federal Department of Mines and Resources (Ells 1948) demonstrate that the Albert Formation (Dawson Settlement Member) locally lies directly on basement. This implies that the Memramcook and McQuade Brook formations must thin to a zero edge as they onlap the irregular basement topography.

The upper boundary of the Dawson Settlement Member with the Frederick Brook Member is interpreted to be gradational. The interpretation is based on the presence of kerogenous shale and mudstone intervals in the Dawson Settlement, which are indistinguishable from analogous lithotypes that dominate the Frederick Brook, and from thin sandstone beds in the Frederick

Brook sequence resembling those in the Dawson Settlement Member.

Lateral Facies Relationships: As noted earlier under ***McQuade Brook Formation***, field relationships and palynological evidence suggest that the upper part of the McQuade Brook Formation and lower part of the Albert Formation (Dawson Settlement Member) are probably temporal equivalents. Well records west and northwest of the Stoney Creek Field indicate that the Albert Formation, including the Dawson Settlement Member, changes facies and laterally interfingers with coarse redbeds of the Steeves Mills Formation (Fig. 13, 14).

Depositional Environment: The sandstone cycles in the Dawson Settlement Member recorded by lithological and gamma-ray logs in the Stoney Creek Field show mainly fining-upward units, which suggest that much of the sand is of fluvial origin. However, the additional presence of coarsening-upward sequences implies that some of the sand was deposited in a deltaic environment. The latter interpretation is entirely consistent with the presence of interstratified kerogenous mudstones and shales, which are undoubtedly the product of deposition in an anoxic stratified lake. Detailed evidence to support a lacustrine depositional environment for the kerogen-bearing rocks of the Albert Formation, particularly the Frederick Brook Member, is given below.

The polymictic conglomerates with interbedded lithic sandstones, mudstones, and minor associated kerogenous shale assigned to the Dawson Settlement Member near Parkindale and Prosser Brook lie adjacent to the Caledonia Uplift. The clast content of the conglomerates and the dominance of coarse clastics suggest that the strata there lie near their source and probably represent braided stream deposits, possibly on the medial part of an alluvial fan. The intercalated beds of kerogenous shales in the conglomeratic sections imply the presence of standing water; accordingly, a fan delta environment is interpreted as the most likely depositional setting. St. Peter (1992) provides a detailed description of the limestones interbedded with coarse clastics near Parkindale. Rounded siliciclastics clasts and grains of algal oncolites bearing cores of ostracod (?) fragments in those carbonate grainstones are taken as evidence of a high-energy beach environment. Such an environment further supports a marginal lacustrine and adjacent upland setting for the Dawson Settlement strata in the Parkindale and Prosser Brook area.

Age: Surface samples, well cuttings, and cores of the Albert Formation have been extensively sampled for palynomorphs. St. Peter and Johnson (2009) compiled information from 136 original assemblages and two studies of reinvestigated assemblages in the report area (Table 3). However, they did not assign each sample a stratigraphic position within the Albert Formation or indicate whether the sample lay in the Dawson Settlement, Frederick Brook, or Hiram Brook member.

The palynological data yield Tournaisian ages possibly as old as Zone 1A and possibly as young as Zone 3A (Fig. 15; St. Peter and Johnson 2009). However, most of the robust and better preserved assemblages provide early to middle Tournaisian ages of Zones 1D to 2. Assemblages giving the earliest Zone 1 dates are all from the area of Saint-Joseph and Taylor Village. For instance, the assemblage from locality 32 (Plate 4) northeast of Saint-Joseph provides a Zone 1A age (Dolby 1991); that in a sample from Well 702 (locality U on Plate 4) at depth 573.6 m suggests a possible Zone 1A age (Dolby 2000a). Southwest of Well 702, the surface sample at locality W gives a tentative Zone 1A age (Dolby 1991), although a restudy of the assemblage (Dolby 2000b) shows that the date was based on the absence of Zone 2 markers.

The geographic restriction of these oldest dates could be interpreted to show that samples in the Saint-Joseph–Taylor Village area derive from the stratigraphically lowest part of the formation (Dawson Settlement Member). In this regard, note that the McQuade Brook Formation lies just north of locality 32 (Plates 3, 4) and east of locality U (Plate 4). However, there must be another explanation. For example, samples from Well 699 (locality T on Plate 4) provide a confident Zone 1D age at depth 169.2 m and a possible Zone 2A age at depth 134 m (Dolby 2000a). These dates agree more closely with the Zone 1C (?)–1D ages assigned to assemblages from the lower beds of the Albert Formation in Well 333 (locality A on Plate 4). It thus appears that the assemblages giving the Zone 1A ages were possibly influenced by climatic or environmental factors and so do not contain the diagnostic Zone 2 markers (compare spore locality W; Dolby 1991, 2000b) needed to give a reliable depositional age. In summary, notwithstanding the anomalously old dates of assemblages from the Saint-Joseph–Taylor Village area, the remaining nearly 140 assemblages indicate the Tournaisian age of the Albert Formation ranges from possibly Zone 1C (definitely Zone 1D) to possibly Zone 3A (definitely Zone 2B). Presumably, the Dawson Settlement Member lies in the oldest (i.e., early Tournaisian) part of this range.

Relationship to Previous Stratigraphy: The Dawson Settlement Member as used herein in a regional sense is closely similar to that originally defined by Greiner (1962). It is interpreted to lie conformably (and probably diachronously) above the McQuade Brook Formation (the upper part of the Memramcook Formation of previous workers) and transitionally below the organic-rich Frederick Brook Member of the Albert Formation as defined by Greiner (1962). The type section of the Dawson Settlement Member in Well 305 is modified slightly herein (see ***Type Section***, above) to more accurately reflect the textural lithological descriptions provided by Greiner (1962) to distinguish the member from the McQuade Brook Formation and Frederick Brook Member. The modification places the Dawson Settlement Member–McQuade Brook Formation contact 25 m higher, and the Dawson Settlement–Frederick Brook member contact 60 m higher, than Greiner's recommendation.

Frederick Brook Member (Albert Formation)

Author: Greiner (1962).

Type Section: Greiner (1962) designates the outcrops of Albert Formation along Frederick Brook about 2 km west of Albert Mines, Albert County (NST 21 H/15; Plate 4), as the type section of the Frederick Brook Member. In fact, the type section comprises only the outcrops along the brook from the fault contact with the Round Hill Formation southwestward to a point about 75 m south of the secondary road where Wright (1922) shows a sandstone bed on his detailed map of the Albert Mines oil shale area (Plate 4). From the base of that sandstone upsection to the south is the Hiram Brook Member.

Reference Sections: Other good exposures are located on the west bank of Memramcook River at Taylor Village and along LeBlanc Creek near Saint-Joseph, Westmorland County

(NTS H/15; Plate 4). The Frederick Brook Member is also fairly well exposed on the north side of the Pollett River Fault along Popple–Intervale Brook about 5 km west of the report area (Park et al. 2007).

Definition and Description: The Frederick Brook Member is the medial member of the early Tournaisian Albert Formation. It represents the deepest water lacustrine strata of the Albert Formation and comprises mostly kerogen-rich and fish-bearing shale (oil shale); kerogenous mudstone and siltstone; and minor sandstone, conglomerate, limestone, and dolostone. The Frederick Brook is gradationally underlain and overlain, respectively, by the Dawson Settlement and Hiram Brook members. West of the Stoney Creek Field (Fig. 6), it intertongues with the coarse alluvial Steeves Mills Formation.

The organic-rich and organic-poor lithotypes in the Frederick Brook Member are described in detail by Smith (1985) and Smith and Gibling (1987). Smith (1985) logged three boreholes, all of which are located in the Moncton Subbasin: two cut the beds at Downing Creek and one cut strata at Frederick Brook. He shows that a complete spectrum of lithotypes exists from very organic-rich, fissile, microlaminated oil shales through to organic-poor, massive, unlaminated mudstones. St. Peter (1992) subsequently designated three organic-rich lithotypes as arbitrary end-members of that spectrum. Those lithotypes — laminated kerogenous mudstone, laminated kerogenous shale (oil shale), and massive kerogenous mudstone — are described below.

1. *Laminated kerogenous mudstone* is the most abundant lithotype in the Frederick Brook Member. It was designated as 'oil shale C' by Smith (1985) and Smith and Gibling (1987) and called 'massive dolomitic marlstone' by King (1963). Excellent exposures of the lithotype occur in the Taylor Village section and along Frederick Brook (King 1963, his Fig. 2: beds 2, 3, 4, and 5; St. Peter 1992).

The laminated kerogenous mudstone is brown and weathers light grey or brown. It is typically parallel laminated with laminae ranging from 0.6 mm to 10 mm in thickness. The rock commonly breaks with a subfissile or platy fracture. The laminae comprise light-coloured silicate and carbonate-rich layers alternating with thinner, dark brown, organic-rich (kerogen) layers. The kerogen laminae are typically discontinuous and, when split parallel to bedding, exist as isolated patches of organic matter. The laminated kerogenous mudstone commonly contains disseminated pyrite grains, pyrite framboids (Smith 1985), siderite nodules, and fish fragments. Ostracods are present in a bed at Downing Creek just south of Dover (St. Peter 1992).

Samples from the boreholes at Downing Creek near Dover and Frederick Brook near Albert Mines (Smith 1985) were subsequently analyzed by Smith et al. (1991) for weight percentages of minerals, macerals, and total organic content (TOC) in the laminated kerogenous mudstones, oil shales, and massive kerogenous mudstones of the Albert Formation (Table 5). Calcite and dolomite are the only significant carbonates in the kerogenous mudstones. The dolomite is likely mainly ankeritic, as Chowdhury and Noble (1989) determined an average ankerite content of 18.3% in 12 other shale samples from the Hillsborough area. Scanning electron microscopy work showed that albite in sandstones of the Albert Formation resulted from diagenetic alteration of detrital plagioclase and potassium feldspar (Chowdhury and Noble 1992). It seems reasonable to interpret a similar paragenesis for albite in the kerogenous mudstones and other organic-rich mudrocks of the Albert Formation.

Table 5. Organic-rich lithotypes of the Albert Formation, showing wt % of minerals (analyzed using X-ray diffraction), macerals (analyzed using fluorescence microscopy), and total organic carbon (TOC). Data is from core sampled near Downing Creek and Frederick Brook and is after Smith et al. (1991).

Minerals (in wt %)	**Laminated Kerogenous Mudstone** (n = 10)	**Laminated Oil Shale** (n = 16)	**Massive Kerogenous Mudstone** (n = 2)
Quartz	9.6	11.5	8.4
Albite	12.4	15.3	8.8
K-spar	5.0	2.2	9.5
Illite	28.7	40.6	38.3
Smectite	2.1	0.9	0.7
Kaolinite	1.6	0.6	0.7
Chlorite	3.4	0.9	1.0
Calcite	8.5	14.2	24.5
Dolomite	15.7	11.1	6.3
Siderite	0.6	1.0	1.4
Analcime	11.1	-	-
Pyrite	4.1	1.0	1.2
Macerals (in wt %)	**Laminated Kerogenous Mudstone** (n = 3)	**Laminated Oil Shale** (n = 16)	**Massive Kerogenous Mudstone** (n = 1)
Lamalginite	51.4	79.6	2.0
Telalginite	0.4	0.9	5.6
Liptodetrinite	42.9	14.4	82.0
Sporinite	3.5	2.3	6.3
Fusinite	1.0	2.3	3.3
Vitrinite	0.8	0.5	0.6
TOC (total organic carbon)	2.92	10.85	7.26

Analcime appears in the laminated kerogenous mudstones in beds with less than 7% total organic carbon (Table 5; Macauley and Ball 1982; Smith 1985; Smith et al. 1991). The organic-poor mudrocks show a discernible inverse relationship between the content of albite and analcime (St. Peter 1992), implying that the analcime may at least in part originate from feldspar. Macauley and Ball (1982) note that analcime is generally associated with mudrocks with low feldspar content. In the Eocene Green River Formation, Colorado, analcime is interpreted to have originated from clays or zeolite precursors in moderately alkaline lake waters (Brobst and Tucker 1973). In the Carboniferous Rocky Brook Formation of western Newfoundland, analcime in fine-grained lacustrine clastics and carbonates is attributed to 1) direct precipitation from lake water or pore water, or 2) reaction of those waters with a clay mineral or plagioclase precursor (Gall and Hyde 1989).

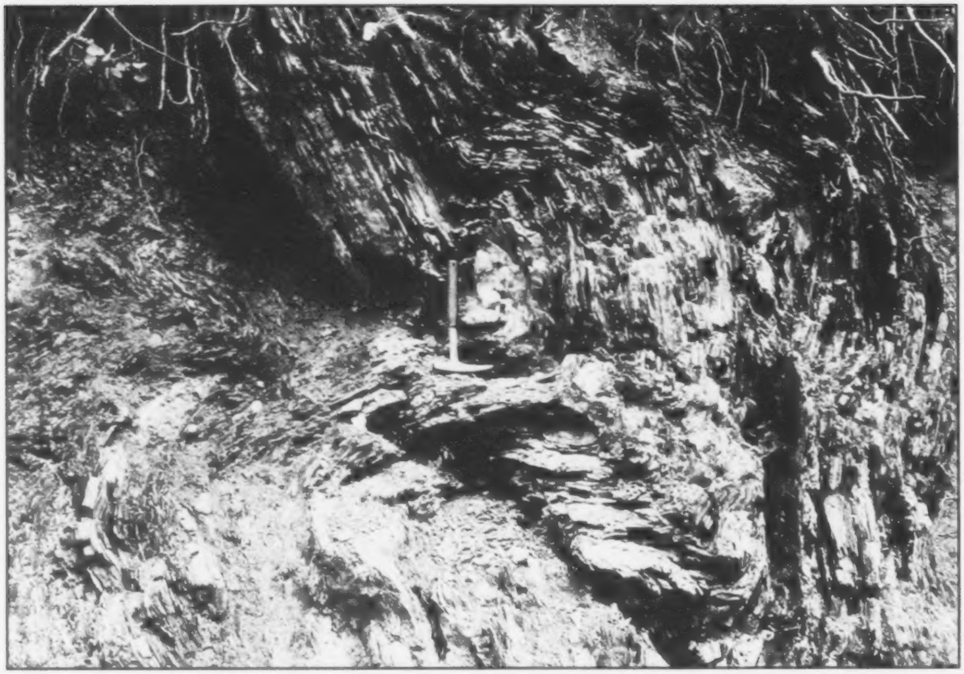


Figure 18. Fissile, microlaminated oil shales of the Frederick Brook Member, Albert Formation, on LeBlanc Creek near Saint-Joseph.

Total organic carbon (TOC) content of the three laminated kerogenous mudstone averages 2.9% (Table 5; Smith et al. 1991). Organic petrography of the same samples indicates that the kerogen laminae are discontinuous and comprise subequal quantities of lamalginite and liptodetrinite.

2. *Kerogenous shale (oil shale)* is the second most abundant organic-bearing lithotype in the Frederick Brook Member. Oil shale is exposed at Frederick Brook about 100 m north of the confluence of its two tributaries (Plate 4). A test pit in this rock was opened by Canadian Occidental Petroleum Ltd. in the field on the east side of Frederick Brook (St. Peter 1988). Organic-rich oil shale is also exposed on the west tributary of Frederick Brook. Oil shale crops out on the north side of the reservoir along LeBlanc Creek (Fig. 18) about 700 m west of Saint-Joseph (Park and St. Peter 2005). The same beds appear on the north side of Boyd Creek (St. Peter 1992) where they were intersected in Well 356. Oil shale in the Rosevale area has been delineated from surface exposures and drill core (Brown and Whaley 1986; St. Peter 1988; St. Peter 1989a, his Plate 89-104C). Correlative oil shales in the Horton Group in Nova Scotia are thoroughly described by Smith and Naylor (1990).

The Albert oil shale beds range in thickness from a few centimetres up to 45 m. The most organic-rich bed at Frederick Brook has an average thickness of 19.8 m with an oil yield of 94.7 L/t (litres/tonne; St. Peter 1988). Beds of comparable thickness and yield are also exposed on the west tributary of Frederick Brook. Other thick, high-yielding beds were drilled at Rosevale, Downey, and Boyd Creek (Macauley and Ball 1982; Smith 1985; Brown and Whaley 1986; St. Peter 1988).

A prominent property of the oil shale beds is their fissility and varve-like or parallel-microlaminated character. The laminae range in thickness from 0.01 mm to 0.7 mm; they comprise tan clay and aphanitic carbonate-rich layers alternating with dark brown kerogen-rich layers. On weathered surfaces the shale alters to a light or medium grey, and the rock splits into fissile sheets, typically no thicker than paper. (King (1963) called these rocks 'paper shales.') Beds of this type at Frederick Brook can yield whole palaeoniscid fish skeletons. Lambe (1909, 1910) gives details of the various fish species, and St. Peter (1987) provides locations of the fish-bearing beds.

The fissile, laminated oil shales at Downing Creek and Frederick Brook contain more calcite and illite but less dolomite than their associated laminated kerogenous mudstones (Table 5). The oil shales contain no analcime; this contrasts with the laminated kerogenous mudstones, which contain about 11% analcime. A thin section of oil shale from Frederick Brook reveals pseudomorphous calcite after an unidentified euhedral cubic mineral. The replaced diagenetic mineral may have been halite. Environmental implications of these results are discussed below.

The average TOC content of the oil shale samples is 10.85%, almost four times that of the laminated kerogenous mudstones (Table 5). Fluorescence microscopy of the same samples shows that the organic-rich laminae comprise mainly lamalginite (79.6%) and subordinate liptodetrinite (14.4%). The fluorescence data indicate that the kerogen is derived mainly from alginitic precursors.

In many places, the parallel continuous laminae of the oil shale beds are disturbed by synsedimentary slump folds that result in highly crenulated and contorted laminations. Loop bedding is also common; it is characterized by a pinching out of a few laminae, with the underlying and overlying laminae showing no disturbance. The phenomenon has been ascribed to dewatering along low-angled planes and may be related to compaction or seismic disruption (Smith and Gibling 1987). Loop bedding has been described in other oil shales (Brobst and Tucker 1973; Gibling et al. 1985).

Syneresis cracks in the oil shales at Frederick Brook resemble conventional mudcracks. However, the former features are narrower, less regular, less polygonal, and commonly radiate from a slightly raised common point. Syneresis cracks have been noted in many other lacustrine shales such as the Eocene Green River Formation (Picard 1966) and the Devonian Caithness Flagstone Series (Donovan and Foster 1972). Propagation of cracks in the Caithness shales has been related to variations in salinity of the overlying waterbody.

Sandstone dykes occur locally in the kerogenous shales and mudstones and were encountered in drill core in the Rosevale area (Brown and Whaley 1986). Surface examples appear at low tide on the east bank of Memramcook River at Upper Dorchester (St. Peter 1992). The outcrop is on the north side of the pier of the old bridge that once crossed the river from Taylor Village. The dykes there are 15 cm to 20 cm wide, strike 15°, and dip vertically. They lie parallel to a prominent set of joints in the kerogenous shales. Both the dykes and joints are offset by later dextral shears possibly related to the Dorchester Fault (Plate 4). Clastic dykes are present in chronologically and lithologically similar rocks of the Horton Bluff Formation in Nova Scotia, where they are interpreted as resulting from inhibited dewatering and probable overpressuring of sand and silt by well-compacted overlying cover rocks (Hesse and Reading 1978).

3. *Massive kerogenous mudstone* is a minor lithotype of the organic-rich lithofacies of the Frederick Brook Member. It is described from core sections by Smith (1985) and Smith and Gibling (1987) from the Downing Creek and Frederick Brook areas and from core near Frederick Brook, Dover, and Rosevale by Macauley and Ball (1982, their Plates 1.c, 3.a). Massive mudstone of this type is also present in the section at Taylor Village (St. Peter 1992).

The massive kerogenous mudstone is light to medium-dark brown. Beds range in thickness from a few centimetres up to intervals 17 m thick (Macauley and Ball 1982). The massive beds show sharp or transitional contacts with beds of laminated kerogenous mudstone or oil shale. A transitional contact from laminated to massive kerogenous mudstone is characterized by a gradual decrease in frequency and continuity of kerogen laminae. The massive kerogenous mudstone has no fissility, and the rock breaks with a blocky habit. Beds of this type commonly contain more silt than do the laminated organic-rich beds (Smith et al. 1991). Like the other organic-rich lithotypes, massive kerogenous mudstone contains dolomite and significant calcite but no analcime (Table 5). Intraformational rip-up clasts of laminated kerogenous mudstone appear in core from the Frederick Brook and Downing Creek areas (Macauley and Ball 1982). The massive kerogenous mudstone beds commonly contain palaeoniscid fish scales, and ostracods are reported from cores at Frederick Brook (Macauley and Ball 1982, p. 148).

Organic matter in the massive kerogenous mudstone is dispersed throughout the mineral matrix. One sample reported in Smith (1985) gives a TOC of 7.26 wt % (Table 5). The 16 samples from Frederick Brook range from 2.44% to 9.75% TOC with a mean of 6.06% (calculated from tabular data in Macauley and Ball 1982, p. 166–168). Fluorescence microscopy shows the predominantly detrital character of the organic matter; 82% of the macerals are liptodetrinite (Table 5).

In addition to the three main lithological units described above, the Frederick Brook Member contains minor interbeds of 1) grey organic-poor shale and mudstone and 2) local beds of sandstone, conglomerate, limestone, and dolostone (Brown and Whaley 1986; St. Peter 1992), each of which are described below.

The *organic-poor shale and mudstone beds* are grey, which distinguishes them from the brown dolomitic kerogenous mudrocks. Bedding thickness ranges from 2 cm to 3 m as estimated from outcrops in the Rosevale area. The grey beds typically contain minor fine-grained calcite but lack dolomite and visible kerogen laminae. Most beds contain parallel laminae of silt or fine-grained sand. Some mudstone beds are massive. The organic-poor mudrocks rarely contain fish scales, but fine-grained plant detritus is quite common in silty mudstones. Some beds show evidence of bioturbation (Brown and Whaley 1986).

Sandstone beds are fairly common in the Frederick Brook Member west of Rosevale but are rare in the section southeast of Boudreau Village and near Saint-Joseph. The sandstones are typically light to medium grey and weather light to dark brown. Sandstone beds west of Saint-Joseph are discoloured by dead oil stains. In most places, the beds are 2 cm to 20 cm thick. An outcrop exposing more than 3 m of sandstone appears at Stuart Brook near Rosevale (Plate 4). The composition and bedforms of the Frederick Brook sandstones are similar to those described for the Dawson Settlement and Hiram Brook members. Most of the sandstones are calcareous and micaceous and vary from quartzose feldspathic arenite to rare beds of lithic wacke. Grain size of individual beds ranges from rarely coarse grained to more typically fine grained. In the Stuart Brook section, 30 cm to 60 cm thick beds are coarse grained and massive at the base and grade upward to fine grained and wave-ripple laminated at the top. Intraformational kerogenous mudstone clasts and coarse-grained lithic detritus are present near the base of some beds. However, many of the sandstone beds are parallel laminated in the lower part and either cross laminated or wave-ripple laminated in the upper part. Fine-grained plant detritus is very common in the sandstones, particularly in the parallel-laminated divisions of beds. A piece of tree trunk 12 cm in diameter occurs in a bed on the upper part of Stuart Brook.

Three lithotypes of *conglomerate* occur in the Frederick Brook Member: polymictic pebble conglomerate, intraformational mudstone breccia, and intraformational sandstone breccia.

- The polymictic pebble conglomerate is grey or greyish green with poorly sorted granules and pebbles of volcanic, plutonic, and metasedimentary rocks in a calcareous sandy matrix. It appears in a few beds (each less than 1 m thick) along tributaries of Turtle Creek near Rosevale (Brown and Whaley 1986), along the unnamed brook southeast of Boudreau Village, and in the subsurface at Frederick Brook (Macauley and Ball 1982, p. 99, 101). The beds probably represent distal parts of coarse tongues that prograded into the deeper part of the lake (St. Peter 1992).

- Intraformational mudstone breccia beds up to 136 cm thick occur in boreholes at Downing Creek and Frederick Brook (Macauley and Ball 1982; Smith 1985). The mudstone breccia comprises angular clasts of massive or laminated kerogenous mudstone or mudstone set in a calcareous, silty mud matrix. The oil shales on Stuart Brook 30 m south of the Hillsborough–Albert formational contact contain a 15 cm thick bed of mudstone-clast breccia in a dolomitic mudstone matrix (Plate 4).

- Intraformational sandstone breccia beds up to 3 m thick appear in cores from the Downing Creek and Rosevale areas (Smith 1985; Brown and Whaley 1986). They contain angular clasts of laminated oil shale or dolomitic kerogenous mudstone in a fine- to medium-grained sandstone matrix (see also Smith and Gibling 1987, their Fig. 3a). The basal contacts of sandy intraformational breccia beds are typically sharp and erosional into underlying mudrocks. The angular intraclasts account for up to 20% of the beds. They are obviously eroded from a partly lithified muddy substratum by a sudden high-energy process that sporadically invades this otherwise low-energy, mud-dominated environment.

Limestone beds ranging from 5 cm to 20 cm thick appear in five exposures of the Frederick Brook Member in the Hillsborough map area (Plate 4): 1) in kerogenous shale on the north side of the LeBlanc Creek reservoir, 2) about 15 m north of the Caledonia Fault on Bray Brook, which lies 2.5 km east of Rosevale, 3) in kerogenous shale on the upper part of Stuart Brook, 4) on the east tributary of Frederick Brook, 125 m south of the confluence of its east and west tributaries, and 5) in kerogenous shale on a small tributary of LeBlanc Creek 300 m west of Saint-Joseph. In all cases, the limestone beds are light or medium grey and weather buff to orangey brown. All three limestone beds at the LeBlanc Creek reservoir contain oncolites up to 8 mm in long dimension. The limestone at Bray Brook is associated with parallel-laminated mudstone and cross-laminated sandstone. The Bray Brook rock is a siliciclastic intraclast grainstone with about 35% angular siliciclastic grains that comprise quartz, quartz–muscovite schist, and felsic volcanic fragments that grade from coarse-grained to very fine-grained sand. The limestone beds at Stuart Brook, Frederick Brook, and LeBlanc Creek appear aphanitic to the unaided eye. At Stuart Brook and LeBlanc Creek, the beds contain vague parallel laminae of unknown but probable algal origin. The latter beds contain fractures and vugs filled with tarry bitumen.

Brown- to orangey brown-weathering, light to medium grey *dolostone beds* are locally present in the Frederick Brook Member at Downing Creek, Frederick Brook, and on the unnamed brook southeast of Boudreau Village. Dolostone beds also occur in drill cores at Downing Creek and Frederick Brook (Macauley and Ball 1982; Smith 1985; Smith and Gibling 1987). Exposed beds are 2 cm to 60 cm thick, and Macauley and Ball (1982, p. 98) report a subsurface dolostone bed near Frederick Brook that is 40 m thick. The dolostone beds range from aphanitic and massive to parallel laminated. The laminae comprise vague, thin, continuous to discontinuous layers of organic matter (kerogen) and siliciclastic layers of silt or fine-grained sand. The dolostone beds show gradational contacts with interbedded dolomitic kerogenous mudstones (Macauley and Ball 1982; Smith 1985). X-ray diffraction results on seven samples of dolostone show a dolomite content of 50% to 84% (Macauley and Ball 1982). The same data show a broad range of dolomite mineral content in dolomitic kerogenous mudstones, dolomitic kerogenous shales, and dolostones, confirming the highly varied composition and intergradational nature of these lithotypes (St. Peter 1992).

Distribution and Thickness: Where the kerogenous beds of the Frederick Brook Member form a fairly thick (tens to hundreds of metres) sequence in the medial part of the Albert Formation, those beds can be assigned with reasonable confidence to the Frederick Brook Member. However, thinner beds of kerogenous mudstone and shale exist in the Dawson Settlement and Hiram Brook members which, in areas of limited outcrops and known or suspected structural complications, can result in equivocal assignment.

In the Moncton Subbasin, the Frederick Brook Member occurs in its type section at Frederick Brook as well as within and adjacent to the Stoney Creek Field (Fig. 13, 14; Greiner 1974; Foley 1989). Elsewhere in the eastern Moncton Subbasin, the member is exposed along Downing Creek south of Dover, along the upper reaches of Boyd Creek, east of the Saint-Joseph Fault along LeBlanc Creek, along the west bank of Memramcook River just east of Taylor Village, along the lower part of an unnamed brook just southeast of Boudreau Village, and along tributaries of West Branch Turtle Creek near Rosevale (St. Peter 1988, 1989a, 1989b). The Frederick Brook Member thins and tongues out west, southwest, and north of the Stoney Creek Field (see ***Lateral Facies Relationships***, below). For example it is encountered just west and southwest of Stoney Creek in Wells 181, 190, and 317 but cannot be recognized in the Albert Formation as drilled in Wells 239, 254, 328, 687, 688, and 705 located farther afield (Fig. 13, 14; Plate 4).

In the Indian Mountain Deformed Zone, the Albert Formation between Pacific Junction and McQuade Brook cannot be clearly divided into members, due to the still-limited knowledge of stratigraphy and structure in the IMDZ (see Greiner 1974; St. Peter 1989b, 2006a; Park and St. Peter 2009). Organic-bearing beds (dolomitic and kerogen-bearing mudstones and shales) are present from the apparently lowest beds in the section adjacent to the O'Neil Fault to the highest part of the formation just below the Indian Mountain Formation (Fig. 10; Park and St. Peter 2009). Their presence, plus the relatively minor content of coarse clastic strata, makes it tempting to interpret the entire sequence in the Indian Mountain area as Frederick Brook Member. However, the kerogenous mudstones and oil shale beds in the IMDZ are not as organically rich as those in the Frederick Brook Member in the Moncton Subbasin (e.g., at Frederick Brook or LeBlanc Creek). Consequently, there is a hesitancy to make the lithological correlation, and the Albert Formation in the IMDZ has not been divided into its respective members.

The Frederick Brook Member at the type section is estimated from bedding attitudes and graphic construction to have a minimum thickness of about 350 m. Wright (1922) gives a thickness estimate for the type section (his zone 2) of about 240 m, but the cross-section on his detailed map of the Albert Mines oil shale area suggests a measure closer to 300 m. The type section is cut by many minor faults (Wright 1922) and bedding-parallel slip surfaces and is also deformed by two phases of folding (St. Peter 1988; Park and St. Peter 2005). Any thickness estimate is therefore tenuous. Greiner (1962) gives a thickness of about 150 m for the member in the Stoney Creek Field. However, the member thins dramatically from the eastern to the western part of the field (Fig. 13) and from the southern to the northern part of the field (Fig. 14). It is only 67 m thick (depth interval 1055–1122 m) in Well 317, located 1 km north of Dawson Settlement (Fig. 13), and must thin to a zero edge just west of there, being absent in the more westerly wells, as noted above.

In the section on lower Downing Creek, the Frederick Brook Member is intersected in Wells 198, 339, 355, and 356. The drill intersections combined with surface bedding attitudes demonstrate a kerogenous mudstone interval about 150 m thick in this area. In Well 337 just northeast of Boudreau Village, a section rich in oil shale is about 200 m thick (Macauley 1981, p. 70). In Well 200 at Rosevale and in the closely adjacent Well 340, a kerogenous facies assigned to the Frederick Brook Member has an estimated thickness of about 100 m.

Lower and Upper Boundaries: Greiner (1962) describes the basal boundary of the Frederick Brook Member with the underlying Dawson Settlement Member as a gradational contact. In the type section of the Dawson Settlement Member in Well 305 (Table 4), the lower boundary of the Frederick Brook Member is placed herein at a depth of 3801 ft (1159 m) at the top of a 5 ft (1.5 m) thick conglomerate bed that sits atop a 45 ft (14 m) thick sandstone interval. (See ***Dawson Settlement Member–Type Section***, earlier, for details of the Dawson Settlement–Frederick Book boundary.) The boundary between the organic-bearing shale unit (Frederick Brook Member) and the interbedded sandstone and shale unit (Dawson Settlement Member) restricts the Frederick Brook Member to dominantly dolomitic and kerogen-bearing mudstone beds, lying above the generally coarser and less organic-bearing Dawson Settlement Member.

The same criteria help to define the upper boundary of the Frederick Brook with the overlying Hiram Brook Member. The top of the Frederick Brook Member is located where the dominant kerogenous mudrocks and shales give way to organic-poor mudrocks, sandstones, or conglomerates. Well records from the Stoney Creek Field indicate that the Frederick Brook–Hiram Brook boundary as thus defined can be either sharp, with a prominent thick sandstone lying on a kerogen-rich section; or it can be transitional, with the kerogenous mudrocks and shales being gradually replaced by organic-lean shales and thinner sandstones.

Lateral Facies Relationships: Lakes in tectonically controlled terrestrial basins vary greatly in size and can range up to continental-scale waterbodies or basins such as those in the modern East African Rift system (Reading 1978; Tiercelin 1990), and the fossil Eocene Green River Formation in Colorado, Utah, and Wyoming (Eugster and Hardie 1975; Ryder et al. 1976). The lake level is a sensitive barometer of climate shifts and tectonic activity; thus, lakes can display frequent and sometimes rapid changes in water budget with consequent repetitive transgressive and regressive cycles (Dean and Fouch 1983; Scholz et al. 1993). The paleolake recorded by rocks of the Albert Formation (see ***Depositional Environment***, below) was situated in a tectonically active setting characterized by relatively small terrestrial basins bounded by intervening crystalline uplifts (Fig. 6, 7, 9). Accordingly, the lacustrine strata in the Albert Formation are expected to show lateral interfingering with their upland terrestrial temporal equivalents. The kerogenous mudstone facies represented by the Frederick Brook Member is interpreted to represent a time when paleolake Albert was at its deepest and probably most areally extensive.

Lithologs for drillholes east and west of Rosevale, as well as adjacent exposures along the tributaries of Turtle Creek, demonstrate the intercalation of coarse upland polymictic conglomerate and lithic sandstone tongues within kerogen-rich lacustrine oil shales of the Frederick Brook Member (Ells 1948; Brown and Whaley 1986; St. Peter 1992; Park et al. 2007). The lateral relationship of the non-lacustrine upland facies to the organic-rich lacustrine facies is shown even more dramatically in Well 328 near Berryton north of Rosevale. The litholog for that well provides an instructive example of the complex lateral facies relationships in the Albert Formation of the eastern Moncton Subbasin. Reddish brown and minor grey mudrocks and sandstone of the McQuade Brook Formation were intersected at 1917.6 m; the McQuade Brook assignment was confirmed by an early Tournaisian Zone 1A–1B age (Dolby 2000b) for analogous rocks in the adjacent Well 705. The Albert above the McQuade Brook in Well 328 is not divisible into its three members as readily as elsewhere but instead is mainly grey mudrocks with lesser intervals of grey sandstone and conglomerate and rare beds of kerogenous shale. A dated spore assemblage of middle Tournaisian Zone 2 at 1693.8 m supports the rocks as being Albert Formation.

Overlying the Albert Formation in Well 328 is the Steeves Mills Formation, consisting of predominantly fine-grained redbeds with lesser sandstone, conglomerate, and grey mudrocks in its lower part. (The Steeves Mills Formation is exposed nowhere on surface in the eastern Moncton Subbasin.) The Albert–Steeves Mills contact is placed at the base of the lowest redbed at 1390 m. A spore assemblage at 1549 m yields a Tournaisian Zone 2A age, whereas two samples uphole at 1424 m and 1294 m provide general Tournaisian Zones 2–3 ages (Dolby 2005). The palynological data and apparently gradational boundary with the Albert Formation strongly support assigning the Steeves Mills Formation to the Horton Group rather than to the late Tournaisian Sussex Group. Moreover, the lithological and palynostratigraphic data force the conclusion that there is no missing Horton section (for example, Albert Formation) above the McQuade Brook Formation in Well 328. Accordingly, the organic-rich mudrocks of the Frederick Brook Member so prevalent at Rosevale, Stoney Creek, and Frederick Brook must tongue out south and east of Berryton. Reiterating the point made above under ***Distribution and Thickness***, the Frederick Brook Member is interpreted to thin dramatically west, southwest, and north of the Stoney Creek Field (Fig. 13, 14) and is absent in wells west of Wells 190 and 317).

Depositional Environment: The Frederick Brook Member is interpreted as a shallow to deep lacustrine sequence (Greiner 1974; Smith 1985; Smith and Gibling 1987; St. Peter 1992). The sections dominated by microlaminated oil shale with well-preserved organic laminae and whole fish fossils evidently represent a very low-energy, deep, anoxic lacustrine environment (Smith 1985; Smith and Gibling 1987). The oil shales show no evidence of bioturbation, suggesting an inhospitable environment for benthos. The rhythmic varve-like character of the laminae may indicate a seasonal or cyclic climatic control on deposition in the deep lacustrine beds. The widespread synsedimentary folds and local intraformational mudstone and sandstone breccias in the laminated oil shale intervals indirectly imply a deep lacustrine setting. The formation of mudstone breccias by what seems to be a slumping process, for example, suggests considerable bathymetric relief. Sandstones with intraformational clasts of laminated oil shale imply a sudden, violent, high-energy transport mechanism — again, possibly indicating substantial water depth.

The kerogenous laminated mudstones contain more siliciclastic silt and less clay and organic matter than do the oil shale beds, which suggests a more shallow-water setting (Picard and High 1972, their Fig. 8). Interbeds of limestone grainstones and wave-ripple-laminated siliciclastic sandstones within kerogenous laminated mudstone intervals indicate deposition above a fair-weather wave base. Algal-laminated limestones, algal oncolites in grainstones, and micritic algal mats in kerogenous mudstones likewise imply a relatively shallow-water environment (St. Peter 1992). Further evidence of the distinction between shallow and deep lacustrine environments in the Albert Formation is given in Carter and Pickerill (1985b), Pickerill et al. (1985), Smith (1985), Smith and Gibling (1987), and St. Peter (1992).

In the Rosevale area, the Frederick Brook Member contains interbeds of polymictic conglomerate (St. Peter 1992; Park et al. 2007). The conglomerates commonly contain accessory clasts of micritic limestone, as seen in thin section. Such clasts typically show pelletoidal and irregular (swirled) laminae interpreted to be of algal origin (St. Peter 1992). The source of the clasts is almost certainly intraformational lacustrine limestone beds. Where the conglomerates are interstratified with kerogenous mudstones or shales, limestone clasts in the conglomerates imply subaqueous erosion and lacustrine deposition.

In the Indian Mountain area, the Albert Formation is not presently divisible into members but contains abundant parallel-laminated, dolomitic, kerogenous mudstones that are interpreted as primarily marginal- to shallow-lacustrine strata (Carter and Pickerill 1985b). The marginal lake–mudflat rocks in this lithofacies commonly display desiccation cracks, attesting to subaerial exposure. There, as in the eastern Moncton Subbasin, the medial Albert Formation is characterized by an organic-rich lacustrine facies, which demonstrates the widespread distribution of lakes during this time.

Age: The age of the Albert Formation has been established by more than 136 spore assemblages (Table 3; see ***Dawson Settlement Member,*** earlier). The formation ranges from possibly early Tournaisian Zone 1C (definitely Zone 1D) to possibly as young as middle

Tournaisian Zone 3A (definitely Zone 2B; Fig. 15). The Frederick Brook Member lies in the medial part of the formation and therefore is presumably restricted to an age of Tournaisian Zone 2 or early middle Tournaisian.

Relationship to Previous Stratigraphy: The thick, abundant oil shale beds along Frederick Brook were known to early geologists (e.g., Gesner 1841) and others before John Duffy discovered the famous albertite vein in 1849 (Dawson 1853, 1868). The oil shales achieved widespread attention by paleontologists in the early 20th century following the discovery and description of whole palaeoniscid fish skeletons at Frederick Brook (Lambe 1909, 1910). The dominance of organic-rich mudrocks in the medial part of the Albert Formation in the eastern Moncton Subbasin was first observed by Wright (1922). Greiner (1962) formally designated these beds the Frederick Brook Member. The Frederick Brook Member as used herein is similar to that originally defined by Greiner (1962) for the type section at Frederick Brook but is restricted to the section of Albert Formation that lies below (north of) the prominent sandstone bed on Wright's (1922) detailed map of the Albert Mines area. The boundaries of the Frederick Brook Member with the Dawson Settlement and Hiram Brook members at their type sections in the Stoney Creek wells (see ***Dawson Settlement Member***, earlier, and ***Hiram Brook Member,*** below) are slightly modified to better reflect Greiner's (1962) textural description of the lithological content of the Frederick Brook Member.

Hiram Brook Member (Albert Formation)

Author: Greiner (1962).

Type Section: Greiner (1962, p. 230–231) designates the interval between 1209 ft and 3286 ft (368.6–1001.8 m) in Well 243 located on the south side of the Stoney Creek Field as the type section of the Hiram Brook Member. The type section is retained herein with the following modifications to the upper and basal contacts of the member with the Gautreau Formation and Frederick Brook Member, respectively. The Gautreau Formation in the well comprises greyish green shale, bluish grey shale and associated minor limestone, gypsum (anhydrite), and thin beds of sandstone. The Hiram Brook Member of the Albert Formation, on the other hand, comprises dark grey shales, organic-bearing shales, and interbedded grey (commonly oil- or gas-bearing) sandstones. In descending the section, the first characteristic Albert lithotype is an organic-bearing shale at 1435 ft (437.5 m). Deeper in the section is a thick interval of sandstone (Hiram Brook Member) from 3204 ft to 3327 ft (976.8–1014.3 m), the base of which defines an obvious contact with a thick sequence of underlying shales and organic shales (Frederick Brook Member).

In summary, the type section of the Hiram Brook Member is modified herein from that of Greiner (1962) to be the interval between 1435 ft and 3327 ft (437.5–1014.3 m) in Well 243 in Albert County (NTS 21 H/15; Plate 4).

Definition and Description: The Hiram Brook Member constitutes the upper unit of the early Tournaisian Albert Formation. It comprises interbedded sequences of fluvial to deltaic sandstones, lacustrine mudstones, and kerogenous shales; and minor beds of conglomerate and rare limestone. Hiram Brook beds gradationally overlie the Frederick Brook Member and, west of the Stoney Creek Field, laterally intertongue with coarse alluvial strata of the Steeves Mills Formation. The upper boundary of the Hiram Brook Member is unconformable or disconformable with the Sussex Group.

The type section of the Hiram Brook Member in Well 243 (Table 6) records the scale and thickness of sandstone and shale intervals that characterize the member in the eastern Moncton Subbasin. As noted above, the type section of the member as designated by Greiner (1962) has been modified to accommodate the redefined Gautreau Formation and to restrict the

Table 6. Summary of the type section for the Hiram Brook Member, Albert Formation, in Well 243, from the company litholog. Well lies on the south side of the Stoney Creek Field. Roman numerals I to IV denote 'Sandstone Packages' discussed below.

Depth (ft)	Depth (ft)	Thick-ness	Description Well location: 45°57'20"N, 64°43'18.3"W and at ground elevation of 75 m
			Gautreau Formation
–	1435	–	Bluish grey and greyish green shale with minor interbeds of limestone and sandstone; minor gypsum
1435	**3327**	**1892**	**Albert Formation: Hiram Brook Member**
1435	1609	174	Shale, minor kerogenous shale, minor fine-grained sandstone
1609	1734	125 **(I)**	Sandstone (40%): grey, brown, and black, fine to medium grained in intervals up to 14 ft thick (oil- and gas-bearing) Shale (60%): non-kerogenous to kerogenous in intervals up to 36 ft thick
1734	1903	169	Shale: non-kerogenous to highly kerogenous; minor thin sandstone
1903	2032	129 **(II)**	Sandstone (60%): grey to black, fine to coarse grained in intervals up to 21 ft thick (oil- and gas-bearing) Shale (40%): non-kerogenous to highly kerogenous in intervals up to 25 ft thick
2032	2381	349	Shale: non-kerogenous to very highly kerogenous Sandstone: one bed at 2099–2110 ft
2381	2683	302 **(III)**	Sandstone (70%): grey to brown, fine to coarse grained in intervals up to 32 ft thick Shale (30%): non-kerogenous to kerogenous in intervals up to 16 ft thick
2683	2786	103	Shale (90%): non-kerogenous Sandstone (20%): as thin beds
2786	2819	33	Sandstone: light grey, fine to medium grained
2819	2944	125	Shale (70%): non-kerogenous to kerogenous Sandstone (30%): grey to brown, fine to medium grained in beds up to 12 ft thick in upper part of interval
2944	3001	57	Sandstone: brown, medium to coarse grained (dry oil sand)
3001	3028	27	Shale: non-kerogenous to kerogenous
3028	3063	35	Sandstone: brown, fine to medium grained with rare shale partings
3063	3084	21	Shale
3084	3144	60	Sandstone (oil sand): fine to medium grained and locally pebbly; thin shale partings
3144	3204	60	Shale: non-kerogenous to kerogenous; minor thin sandstone beds
3204	3327	123 **(IV)**	Sandstone (oil sand): light grey to brown, fine to coarse grained and locally pebbly; minor thin shale beds
			Albert Formation: Frederick Brook Member
3327	–	–	Shale and kerogenous shale

underlying Frederick Brook Member to primarily an organic-rich lithofacies. The original company litholog (Table 6) gives the interval depths in feet, which are retained here. The non-oil-bearing sandstones (Table 6) are typically light to medium grey and slightly calcareous; oil-bearing sandstones are typically brown to black; shales are typically grey to nearly black and slightly calcareous; and kerogenous shales are more typically greyish brown and dolomitic.

The type section records the cyclicity of sandstone and shale in the Hiram Brook Member and the fact that sandstone-dominated intervals commonly exceed 100 ft (30 m) thick. During the early extensive drilling program in the Stoney Creek Field, the prominent sandstone 'packages' in the Albert Formation were assigned Roman numerals from I at the top of the formation to VI at the base (Henderson 1940; Howie 1968). Data from the many Stoney Creek wells suggest that the upper four sandstone packages (I to IV) assignable to the Hiram Brook Member could be correlated with some certainty among wells in the field area (Table 6). Interestingly, the drillers' fifth sand (sand V) was not sand at all but instead was kerogenous shales and kerogenous mudstones of the underlying Frederick Brook Member. Sand VI was arbitrarily and inadequately described as the main sand body that occurs below the Frederick Brook Member.

Surface exposures of, and oil and gas exploration wells cutting, the Hiram Brook Formation in the eastern Moncton Subbasin also record the cyclicity of sandstone and shale intervals in the member. St. Peter (1989b) produced a series of lithofacies maps of the Albert Formation that showed surface exposures containing significant sandstone-dominated intervals versus those containing shales and relatively minor sandstone.

Sandstone-dominated sections: The best exposed sandstone-dominated section in the report area lies along Boyd Creek in the vicinity of spore localities 33, 34, and 35 (Plate 4). The section is about 170 m thick and therefore is comparable with the thickest drilled sandstone package at Stoney Creek. Another section containing several outcrops of sandstone appears on the upper part of Frederick Brook, south of the Edgetts Landing Fault (Plate 4). The south end of the section on the east side of Petitcodiac River at Boudreau Village is also dominantly sandstone with interbedded dark grey shale (Fig. 19).

Sandstone in the sandstone-dominated sections is typically medium grey and weathers grey, buff, or brown. The brown coloration is commonly a result of impregnation by bitumen, the presence of which causes the freshly broken rock to emit a distinct petroliferous odour. Most of the sandstone beds are fine or medium grained; very fine-grained and coarse-grained beds occur locally. The sand grains are typically moderately well sorted and characteristically comprise greater than 50% quartz detritus. This distinguishes the sandstones from the quartz-poor sandstones associated with polymictic conglomerates of the Dawson Settlement Member. In addition to quartz, the sandstones contain feldspar grains and labile clasts. The clasts include muscovite, biotite, mica schist, mica phyllite, felsic and mafic volcanic rocks, as well as accessory chlorite, rutile, hornblende, and opaque minerals. Nodules and disseminations of pyrite occur in some layers. Felsic volcanic fragments and feldspar commonly show extensive alteration to calcite and clay minerals. The sandstones contain less than 15% matrix by volume and accordingly fall into the quartzose feldspathic arenite and quartzose lithic arenite fields of the sandstone classification of Blackburn et al. (1978). The

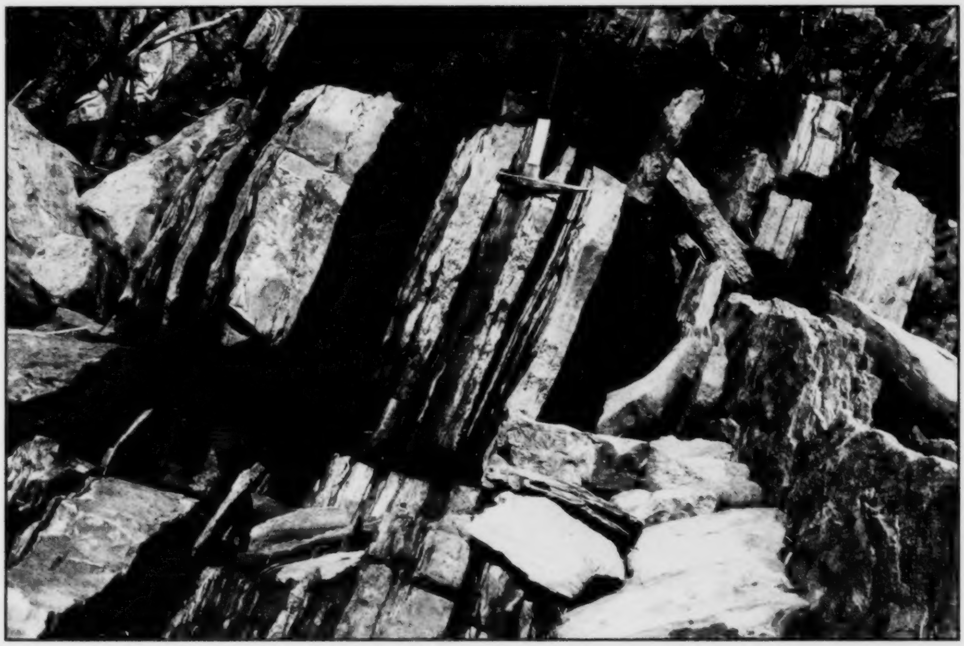


Figure 19. Thin- to medium-bedded, light grey sandstone interbedded with dark grey shale of the Hiram Brook Member, Albert Formation, on the east side of Petitcodiac River near Boudreau Village.

matrix is composed of mainly microspar to sparry calcite, chlorite, and lesser iron oxides in addition to optically indistinguishable clay mineral(s).

The sandstone beds range in thickness from 1 cm to 25 cm. Beds are commonly laid down one atop the other forming amalgamated intervals 1 m to several tens of metres thick. Individual beds display a variety of sedimentary structures including parallel laminations, wavy parallel laminations, wave-formed ripples, interference wave ripples, current-formed ripples, climbing current ripples, cross-laminations, and small-scale tabular cross-beds. Parting lineation and load casts appear at the base of some beds in the Boyd Creek section. Laminations and ripples of all types are typically defined by dark laminae less than 1 mm thick alternating with pale laminae of greater thickness. The darker laminations are enriched in biotite, muscovite, and opaques; the paler ones contain abundant quartz and feldspar. Where the rock splits along bedding, a sheen is evident due to bedding-parallel mica and is a distinctive characteristic of sandstones in the Albert Formation. Plant fragments are also locally abundant on bedding surfaces.

The sandstone beds are characterized by several recurring bedforms. Many beds comprise a parallel-laminated lower part with a wave-ripple-laminated or current-ripple–cross-laminated upper part. Some beds in the Boudreau Village section grade from coarse grained and tabular cross bedded near the base to finer grained and parallel laminated near the top. Climbing ripple-drift cross-laminations (Jopling and Walker 1968, their Types A and B) appear in the beds at Boudreau Village and Frederick Brook. Several sandstone beds in the section along Boyd Creek grade from medium grained at the base to very fine grained at the top. The graded beds typically contain angular intraclasts (rip-up clasts) of dark grey mudstone near their base, suggesting rapid local erosion and deposition. Such graded beds are interstratified with sands showing wave-ripple laminations. The sandstone lithofacies contains minor thin beds of dark grey mudstone and kerogenous mudstone at Frederick Brook, Boudreau Village, and Boyd Creek. The mudstone strata range in thickness from 1 cm up to intervals 5 m thick. Mudstones at Boudreau Village show mudcracks.

The sandstone sections along Frederick Brook and near Boudreau Village contain thin beds of limestone. The limestone at Frederick Brook occurs at three stratigraphic positions in the sandstone section: at the base, 100 m above the base, and 190 m above the base. All limestone beds range from 2 cm to 20 cm thick and appear over intervals up to 3 m thick. They comprise light grey, buff-weathering micritic mudstone and siliciclastic-rich carbonate grainstones and are typically interbedded with mudstone or kerogenous mudstone. The mudstone beds consist of subtle micrite- and microspar-rich parallel laminae. The micrite occurs in three morphological forms: 1) as diffuse peloids, 2) as irregular 'patches,' and 3) as envelopes around blade- to wave-shaped bodies that have a central core of microspar or spar. The micrite probably represents algal remains, and the blade-like structures may represent the remains of phylloid algae. Detritus in the carbonate grainstone beds consists of 20% fine to very coarse sand grains of quartz, chert, and shale, 30% quartz silt, and accessory oncolites all set in a calcite cement. The oncolites range in size from 1 mm to 6 mm along their longest dimension. Some are spherical, but many are elliptical or sausage shaped and comprise layers of calcite enveloping a central sand grain.

The sandstone section on the east side of Petitcodiac River near Boudreau Village also contains a few interbeds of carbonate mudstone and siliciclastic-rich carbonate grainstone. The limestone beds there differ from those at Frederick Brook in the following ways. Many of the carbonate mudstone beds at Boudreau Village show well-preserved mudcracks, and some display rainprints. Coarse-grained grainstone fills the cracks of some desiccated mudbeds. Beds of grainstone are up to 12 cm thick and typically pinch out over a few metres. The grainstone layers invariably contain siliciclastic detritus and carbonate mudstone intraclasts, the latter ranging up to 2 cm in length. Those grainstone beds containing abundant angular mud chips are probably the result of erosion of intensely desiccated mudstone interbeds.

In places, the sandstone-dominated intervals contain minor interbeds of conglomerate. The beds are not observed in surface exposures but are present in the subsurface in Well 239 located 2 km north of Baltimore Station and Well 328 just north of Berryton. The clast composition and texture of the conglomerate in the well cuttings suggest the beds are similar to conglomerates in the Dawson Settlement Member (St. Peter 1992).

Other lithofacies: Between the sandstone-dominated intervals of Hiram Brook Formation are thick intervals that comprise mainly mudstone and lesser sandstone. These sequences are described by St. Peter (1992) as *mudstone lithofacies* and *mudstone–sandstone lithofacies*. They consist of abundant grey mudstone and brown kerogenous mudstone; subordinate feldspathic and lithic sandstone; and minor conglomerate, kerogenous shale, nodular limestone, and oncolitic limestone. The best exposures crop out along three streams east of Petitcodiac River: Downing Creek, Boyd Creek, and an unnamed creek about 600 m northeast of Boudreau Village. The mudstone that characterizes these sequences appears in beds that are from a few centimetres up to several tens of metres thick. Beds range from massive to subfissile to fissile (shale). The most common laminae are continuous to lenticular, parallel layers of silt or fine-grained sandstone. Current- or wave-rippled silt and sand laminations are locally observed. The mudstones are typically medium grey and slightly or moderately calcareous.

Smith (1985) conducted X-ray diffraction analyses of 21 samples of the Albert mudstones to determine their inorganic composition. Analysis results give average values for illite (26.2%), chlorite (7.2%), smectite (3.9%), kaolinite (3.6%), albite (16.4%), potassium feldspar (3.1%), quartz (7.9%), analcime (9.6%), dolomite (13.1%), calcite (5.1%), and pyrite (0.6%). Pyrite is typically present as small nodules or disseminated grains in grey mudrocks. Quartz and feldspar minerals are restricted mainly to silt and sand laminations. Analcime occurs in grey mudstones with less than 7% TOC (Macauley and Ball 1982; Smith 1985). Mossman et al. (1987) report an organic carbon content of 0.73 wt % from 22 samples of "organic-poor" mudrocks (Smith et al. 1991). Beds of brown, dolomitic, kerogenous mudstone, and lesser kerogenous shale occur within the mudstone-dominated intervals and are generally a few centimetres thick and less commonly several metres thick. These lithotypes typically grade into the inorganic-poor mudstones and are indistinguishable from analogous rocks in the Frederick Brook Member.

Sandstone is the most significant minor lithotype in the mudstone facies. It is typically grey but where impregnated by oil may be brown or even black. The sandstone occurs in beds 1 cm to 40 cm thick. The small size of most outcrops precludes making a clear statement of the three-dimensional shape of sandstone beds. Most beds have parallel lower and upper contacts, but lenticular beds were observed. The basal contact of most sandstone beds is sharp. Mudstone intraclasts in some beds indicate local erosional bases. Basal load casts are rare. The upper contact of sandstone layers is either sharp or gradational into overlying mudstone. The sandstones are very fine grained to medium grained and are slightly or moderately calcareous, most showing abundant detrital mica on bedding surfaces. Plant fragments are abundant on some bedding planes. The sandstones generally contain abundant quartz, feldspar, and lithic clasts set in a matrix of carbonate, chlorite, and minor optically unresolvable clay minerals. Massive and normally graded sandstone beds occur locally, but most of the beds are laminated. Typically, bases of the beds show parallel laminations, and the upper parts show current- or wave-generated ripples. The current-generated structures are evident as cross-laminae with a consistent unidirectional foreset sense or as asymmetrical ripples. Wave-generated structures are apparent from 1) cross-laminations with opposing foreset directions in individual beds, 2) bundle-wise upbuilding of cross-laminae into symmetrical ripples (de Raaf et al. 1977), and 3) interference ripple marks.

The mudstone lithofacies locally contains beds of coarse-grained sandstone or pebble conglomerate. Strata of this type range from 2 cm to 100 cm thick. The bases of such beds are typically sharp or erosional into underlying mudstone. The beds of coarse sandstone and conglomerate are similar to those in the sandstone-dominated sections (see above).

In the eastern Moncton Subbasin, the Hiram Brook Member comprises mostly shales and sandstones as noted above. However, west of the report area near Elgin, about 12 km southwest of Parkindale (Fig. 6), the Hiram Brook Member contains significant repetitive fining-upward cycles of polymictic conglomerate, granular to coarse-grained lithic sandstones, finer grained sandstones, mudrocks, and rare kerogenous shale. The beds in that area are described in detail by Park et al. (2007).

Distribution and Thickness: In the eastern Moncton Subbasin, the Hiram Brook Member is widely distributed in and adjacent to the Stoney Creek Field where its type section is located. Sandstones within the member are the main gas-bearing reservoir beds in the field (Fig. 13, 14). East of Stoney Creek, exposed beds of the Hiram Brook Member overlie the Frederick Brook Member along the lower part of Downing Creek, north of the Gautreau Formation on Boyd Creek, west of the Saint-Joseph Fault on LeBlanc Creek, and on the east bank of Petitcodiac River at the south end of the section at Boudreau Village (Plate 4). At Frederick Brook, sandstones and shales of the Hiram Brook Member overlie the Frederick Brook type section south of the Edgetts Landing Fault and the secondary road that crosses the stream (Fig. 14; Plate 4).

In the type section in Well 243, the Hiram Brook Member lies in the interval between 1435 ft and 3327 ft (437.5–1014.3 m), giving a drill thickness of 576.8 m. Three cores from the member in the well show a dip of about 15°, and seismic reflection profiles show the dip is to the south. The true thickness is estimated at 560 m. In the central part of the field in Well 331, the Hiram Brook Member is up to 800 m thick (Fig. 14). An incomplete section at Frederick Brook (Wright 1922, his zone 3 of the Albert Formation) is estimated at about 365 m thick.

Lower and Upper Boundaries: Evidence for the conformable and gradational nature of the lower boundary of the Hiram Brook Member with the Frederick Brook Member was described earlier under ***Frederick Brook Member***. The upper boundary of the Hiram Brook Member, or more generally the upper boundary of the Albert Formation, is not so easily discerned and varies from area to area, depending on the age of the overlying unit. In the Indian Mountain Deformed Zone (Fig. 10), the Albert Formation is concordantly succeeded by the Indian Mountain Formation (details later under ***Indian Mountain Formation***). In the subsurface west and southwest of the Stoney Creek Field, the Albert Formation is gradationally and conformably overlain by red and grey clastic rocks of the Steeves Mills Formation (details later under ***Steeves Mills Formation***). In the eastern part of the Stoney Creek Field, the Hiram Brook Member is disconformably overlain by the Gautreau Formation. That relationship also holds at Boyd Creek and in the subsurface in the Weldon area. Farther south at Boudreau Village, the Hiram Brook Member is unconformably overlain by the Round Hill Formation, an unconformity that also apparently defined the contact with the Albert Formation (prior to faulting) from Boudreau Village west to Caledonia Mountain (Plate 4). Between Caledonia Mountain and Prosser Brook, the Sussex Group is largely missing, and the Albert is unconformably overlain by the Hillsborough Formation. Even more section is missing south of Parkindale where the Albert Formation (Dawson Settlement Member) is unconformably succeeded by either the Mabou Group or the Cumberland Group.

Lateral Facies Relationships: The Hiram Brook Member west of the Stoney Creek Field must be in part laterally equivalent to the Frederick Brook Member, as the Frederick Brook thins to a zero edge west of Wells 181 and 317 (Fig. 13, 14). Also, northwest, west, and southwest of the Stoney Creek Field, the grey sandstone and mudrock cycles that characterize the Hiram Brook Member in the field are laterally replaced by a unit of red and grey rocks comprising conglomerates, sandstones, and shales. That unit, the newly defined Steeves Mills Formation, contains enough thin tongues of characteristic Albert grey micaceous sandstone, kerogenous mudstones, and dolostones to make the lateral correlation with the Albert Formation (Fig. 13, 14). The lateral lithostratigraphic relationship was implied by St. Peter (1992, his Fig. 31 and Plate 92-36) via a facies change from fine-grained clastics at Stoney Creek to coarser clastics (St. Peter's facies **Ac**) west and southwest of the field. The ages of palynological assemblages from the Steeves Mills Formation support a correlation with the upper part of the Albert Formation.

Depositional Environment: The thick sandstone-dominated lithofacies of the Hiram Brook Member is interpreted to have been deposited in a marginal lacustrine environment. The facies shows evidence of local subaerial and widespread subaqueous deposition, implying that sedimentation took place near a lacustrine strand. The facts that the sandstones lie within mudstones and kerogenous mudstones of undoubted lacustrine origin and commonly display wave-formed ripples and cross-laminations showing no obvious paleocurrent maxima (St. Peter 1992) strongly indicate deposition mainly above the storm wave base. The algal-laminated limestone and oncolitic limestone beds in the sandstone sequences also support a shallow lacustrine setting (Osborne et al. 1982).

The fine- to medium-grained sandstone intervals at the Stoney Creek Field were ascribed a deltaic origin by Greiner (1962, p. 234) and Howie (1968) and a fluvial–deltaic origin by Pickerill et al. (1985, p. 29–30). However, wells drilled recently in the field such as Wells 331 and 332 show no coarsening-upward cycles, such as would be expected for a prograding river- or wave-dominated delta (Friedman and Sanders 1978; Miall 1979, 1984). Instead, lithologs of ditch cuttings from Well 331 demonstrate two types of cycles: 1) fining-upward, and 2) coarsening-upward to fining-upward (St. Peter 1992). The absence of solitary coarsening-upward cycles suggests that the Stoney Creek sandstones are not river- or wave-dominated deltas in the classical sense (Miall 1979, 1984). In addition, the absence of typical delta topset beds (coarse sandstones and conglomerates, oxidized redbed mudstones, paleosols, or back-swamp marsh deposits) argues against a deltaic origin (Miall 1984). The fining-upward and coarsening-upward to fining-upward cycles in well cuttings at Stoney Creek are therefore interpreted as transgressive (i.e., waning energy) and regressive–transgressive cycles, respectively (St. Peter 1992).

The mudstone-dominated cycles in the Hiram Brook Member are interpreted as nearshore and shallow lacustrine sequences (Pickerill and Carter 1980; Carter 1985; Carter and Pickerill 1985b). A relatively low-energy lacustrine setting is indicated for those grey mudstones and silty parallel-laminated mudstones associated with brown calcareous and dolomitic kerogenous mudstones. The mudstones and, particularly, the kerogenous mudstones commonly contain rhomboid, black vitreous scales of freshwater palaeoniscid fish (Lambe 1909; Greiner 1974, 1977). The disarticulation of fish implies higher energy conditions in this environment than in the deep lacustrine setting of the microlaminated kerogenous shales of the Frederick Brook Member. Further evidence that the mudstone facies in large part represents shallow lacustrine sedimentation is shown by wave-formed ripples in interbedded sandstones.

Some of the mudstone facies is interpreted to have been deposited mainly on mudflats near the margin of a lake. The mudstone intervals that contain no kerogenous interbeds suggest deposition on mudflats, perhaps representing the most distal part of an alluvial fan. The mudflat environment is more convincingly demonstrated where there are thin, graded sandstone beds bearing current ripples, implying sheetwash deposition.

Age: The age of the Albert Formation has been established by more than 136 spore assemblages (Table 3; see ***Dawson Settlement Member,*** earlier). The formation ranges from possibly Tournaisian Zone 1C (definitely Zone 1D) to possibly as young as Zone 3A (definitely Zone 2B; Fig. 15). The Hiram Brook Member defines the upper part of the formation and has yielded ages of middle Tournaisian Zones 2 and 3A (St. Peter and Johnson 2009).

Relationship to Previous Stratigraphy: Greiner (1962) defined the Hiram Brook Member as grey clastic rocks overlying organic-bearing mudstones and shales of the Frederick Brook Member. His definition is retained, but his selected type section in Well 243 is modified herein to 1) more accurately state the depth intervals of the main sandstone and mudstone intervals in the member, 2) nominate the contact with the Frederick Brook Member at a significant sandstone–kerogenous shale break, and 3) more carefully establish the contact with the overlying Gautreau Formation on the basis of the contrast in lithotypes between the Gautreau and Albert formations.

Steeves Mills Formation

Authors: New name introduced herein.

Type Section: The type section is designated herein as the interval in Well 688 from the base of the Hopewell Cape Formation at a depth of 310 m to the top of the McQuade Brook Formation at a depth of 1277 m (Fig. 13). The well is located about 1 km southeast of Baltimore Station, Albert County (NTS 21 H/15; Plate 4).

Reference Sections: The relationship of the Steeves Mills Formation with the Albert Formation is convincingly shown in a reference section in Well 254, located 3.5 km northeast of Baltimore Station (Fig. 14). The contacts with the underlying Albert Formation and overlying Round Hill Formation are also clearly apparent in Well 705 situated 1.5 km north of Berryton. Both wells are located in map quadrant NTS 21 H/15 (Plate 4).

Definition and Description: The Steeves Mills Formation is a middle Tournaisian sequence of mainly coarse-grained alluvial redbeds that gradationally overlie and laterally interfinger with the Albert Formation in the subsurface west of the Stoney Creek Field (Fig. 6). The name 'Steeves Mills Formation' is formally introduced herein for this unit, which is unconformably succeeded by formations of the Windsor and Mabou groups.

The Steeves Mills Formation is known only from borehole records, not surface exposures. The earliest indications of the unit came from gas and oil exploration wells drilled on the western side of the Stoney Creek Field in 1912. The lateral relationship of the Steeves Mills and Albert formations can be demonstrated in Wells 239 and 254 (Fig. 14; Plate 4), where two 20 m to 35 m thick tongues of grey sandstone and minor associated kerogenous, fish scale-bearing mudstones of obvious Albert affinity are separated by a 200 m thick tongue of Steeves Mills red coarse conglomerates, grits, and mudstones. Superposition of the Steeves Mills Formation is shown in Well 317, located 1 km north of Dawson Settlement (Fig. 13), where characteristic grey Albert strata below a depth of 631 m are overlain concordantly by a sequence of red mudstones and interstratified fine- to coarse-grained lithic sandstones and conglomerates.

Well 687 and nearby Well 688 were drilled near Steeves Mills in late 1997 (Fig. 13). It soon became apparent that stratigraphic relationships in the area were not understood well enough to explain the perplexing lithological data retrieved from those wells. The wells were drilled to test the western strike extension of the gas- and oil-bearing Albert reservoir sandstones of the Stoney Creek Field. Company lithologs did not initially identify the Albert Formation, despite the fact that Well 688 cut the McQuade Brook Formation at 1277 m. A more thorough relogging discerned the presence of narrow intervals of grey micaceous sandstone, grey shale, and kerogenous limestone of characteristic Albert affinity in the lower 300 m to 400 m of an otherwise 'redbed' sequence of non-Albert aspect. That sequence contains pink, red, and grey sandstone and conglomerate, and red and minor grey mudstone. The upper approximately 600 m of the sequence carries no recognizable lithology typical of the Albert Formation.

The lithological sections in Wells 687 and 688 have thus come to be interpreted as follows: 1) the strata lying on the McQuade Brook Formation is laterally equivalent to the Albert Formation and to the redbeds that overlie it (for example, the beds in Well 317; Fig. 13), and 2) the redbeds that overlie and interfinger with the Albert Formation are herein named the Steeves Mills Formation in recognition of where their problematic identity was first appreciated.

The following summary is taken mainly from lithological descriptions and graphical representations of company well logs, supplemented in part by examination of well cuttings by one of us (CSP). At Well 688, the formation is divided into two parts: a lower part from 823 m to 1277 m and an upper part from 310 m to 823 m. The lower part comprises intervals up to 40 m thick of grey and pink, polymictic conglomerate and lesser grey and pink feldspar-rich sandstone interstratified with minor mudstone and shale intervals that are typically 2 m to 6 m thick. The mudstone–shale layers are reddish brown in the lower portion and grey to dark grey in the upper portion of the lower part. Two tongues of dark grey shale and bituminous limestone occur between 823 m and 838 m, and between 883 m and 895 m. They are comparable with lithotypes in the Albert Formation.

The upper part of the formation is also mostly light pink to reddish brown, polymictic conglomerate and lesser sandstone, forming intervals up to 25 m thick. The coarse rocks are interstratified with minor reddish brown mudstone intervals less than 5 m thick. Beds of grey and dark grey shale are rare. The abundance of pink feldspar and plutonic detritus in the coarse clastics distinguishes these rocks from temporally equivalent Albert rocks adjacent to the Caledonia Uplift, which typically are more dominated by volcanic detritus. The company litholog for Well 317 describes clasts of quartz, feldspar, quartzite, diorite, schist, slate, and limestone in the sandstones and conglomerates of the Steeves Mills Formation, which further differentiates those beds from Horton rocks on the southern margin of the Moncton Subbasin.

The Steeves Mills Formation in Well 254 consists of repetitive intervals of pink, red, and green massive conglomerate and granular sandstone. The conglomerate–sandstone intervals are several tens of metres thick and are separated by beds of red mudstone, which are thin in the lower part and thicker in the upper part of the formation. In depth interval 299 m to 327 m, the coarse redbeds contain an anomalous tongue of grey, fine- to coarse-grained feldspathic sandstone and minor associated slightly kerogenous mudstone, lithotypes comparable with those in the Albert Formation.

In Well 705, the Steeves Mills Formation is formed of subequal quantities of sandstone and mudstone, each in intervals up to 20 m thick. The company litholog describes the sandstones as mostly grey to brown, with fine- to medium-grained beds in the lower part and some coarse-grained beds in the upper part of the formation. The mudstone intervals are predominantly red but show minor grey and green sections. Granular and poorly sorted pebble conglomerate in intervals up to 5 m thick in the lower and medial parts of the formation account for about 10% of the Steeves Mills Formation in this well. The company logger notes quartz and mafic rock fragments in the conglomerate beds, whereas correlated conglomerates in the adjacent Well 328 are described as having numerous limestone pebbles.

Distribution and Thickness: In Well 254, the Steeves Mills Formation overlies the Albert Formation, which in turn overlies coarse rocks of the Memramcook Formation, thus reducing the Albert to a single tongue of grey sandstone and minor shale (Fig. 14). The Steeves Mills Formation does not occur farther northeast at Scotts Hill in Well 405. It may have overlain the Albert Formation in the latter well, but if so it was eroded at the unconformity at the base of the Hopewell Cape Formation. The Steeves Mills Formation also overlies and interfingers with the Albert Formation in wells just east of Stoney Creek Station (Fig. 13; Plate 4).

The subsurface distribution of the Steeves Mills Formation near Stoney Creek Station can be appreciated by examining cross-sections of the Stoney Creek Field by Foley (1989). He separates redbeds that overlie the Albert Formation in that location but interprets the redbeds as Hillsborough Formation. As noted above, the Steeves Mills Formation replaces the Albert Formation in Wells 687 and 688 and is the only Horton unit in Well 172, situated at Baltimore Station. (The absence of Albert Formation in Well 172, drilled in 1912, was likely a significant factor in the discontinuance of westerly drilling in the early exploration of the Stoney Creek Field.)

In Well 319 just west of the community of Turtle Creek, 482 m of coarse redbeds were cut below the Hillsborough Formation contact at 1067 m. Although it is unknown whether the coarse redbeds represent the Memramcook Formation (i.e., the basal unit of the Horton Group) or the Steeves Mills Formation, they are interpreted as the former on Figure 13. Southwest of the Stoney Creek Field near Berryton, the Steeves Mills Formation overlies the Albert Formation in Wells 328 and 705. The Steeves Mills appears to have replaced the upper part of the Albert in both wells; there, the Albert rests on the McQuade Brook Formation but is only 500 m to 700 m thick, considerably thinner than it is farther south and east in the Moncton Subbasin.

A drill thickness of about 970 m is recorded for the Steeves Mills Formation at the type section in Well 688 (Fig. 13). The thickness is estimated because the upper boundary of the Steeves Mills redbeds with the overlying Hopewell Cape redbeds is difficult to pick precisely. The basal contact with the McQuade Brook Formation is established at 1277 m. Some assistance is offered in this regard by the Chevron Canada Resources Limited–Irving Oil Limited seismic reflection line 64YR adjacent to the well (Plate 4). It is used to interpret the basal Hopewell Cape unconformity at about 310 m below surface. Other seismic lines near Well 688 show a relatively shallow dip of the Steeves Mills beds in the area, suggesting a true formation thickness of at least 900 m. In Well 317 east of Wells 687 and 688, the Steeves Mills Formation lies on the Albert Formation at a depth of 631 m and is overlain by the

Hopewell Cape Formation at 396 m. A shallow southerly dip of the section in that area implies a true formational thickness of about 200 m. A comparison of the Steeves Mills Formation in Wells 317 and 688 shows a fourfold increase in thickness from east to west over a lateral distance of 2 km. Recall, too, that the Frederick Brook Member (Albert Formation) in Well 317 tongues out between Wells 317 and 688 to the extent that it is absent in Wells 687 and 688 (Fig. 13).

The drill thickness of the Steeves Mills Formation in Well 705 near Berryton is 355 m as measured from the base of the Round Hill Formation at 696 m (sub-Kelly) to the top of the Albert Formation at 1051 m (sub-Kelly). The well was drilled on Chevron–Irving seismic line 83Y, as was Well 328 (Plate 4). Strong continuous seismic reflectors on that line between the two wells show a stratal dip of about 20° to suggest a true thickness for the Steeves Mills Formation in that area of about 335 m.

Lower and Upper Boundaries: Well records on the western side of the Stoney Creek Field show with near certainty that the 'redbeds' of the Steeves Mills Formation overlie the grey Albert Formation and fairly immediately interfinger farther west with and ultimately replace the Albert grey sandstones and kerogenous mudrocks (Fig. 13, 14). The lateral intertonguing relationship of the Steeves Mills with the Albert results in a transitional boundary between the formations. For convenience the diachronous basal boundary of the Steeves Mills is placed in ascending well sections at the base of the first fining-upward cycle that bears a capping red mudstone interval.

Stratigraphic relationships among the formations of the Horton Group west and northwest of the Stoney Creek Field strongly suggest that the McQuade Brook and Albert formations tongue out not much farther west than the area of Wells 172, 239, and 254 (Fig. 13, 14; Plate 4). Under this scenario, redbeds at the top of the Horton Group (the Steeves Mills Formation) sit atop redbeds at the base of the Horton Group (Memramcook Formation), making it challenging to define a defensible boundary between the upper and lower redbeds. It is therefore proposed that the entire sequence of Horton redbeds there, from the basement upward, be designated as the Memramcook Formation. The coarse redbeds below the Hillsborough Formation (Windsor Group) in Well 319 west of Turtle Creek may represent this scenario (Fig. 13).

Because the Steeves Mills Formation is the youngest Horton formation in the area, its upper contact is defined by unconformities. In the northern part of its distribution area it is overlain by the Hopewell Cape Formation. From Dawson Settlement to Berryton it is succeeded by the Sussex Group.

Lateral Facies Relationships: The facies relationship of the coarse redbeds of the Steeves Mills Formation to the finer grained grey rocks of the Albert Formation is described by St. Peter (1992). In that report, rocks designated herein as Steeves Mills Formation were described as a coarse alluvial facies (**Ac**) of the Albert Formation (St. Peter 1992, his Plate 92-36). Well logs demonstrate that the formation, dominantly conglomerate and coarse sandstone in the western part of its distribution area, becomes progressively finer toward the east. The spatial distribution of the coarse to fine facies suggests that the source of the Steeves Mills detritus was from the west or northwest. This interpretation is supported by the clast content in the conglomerate and sandstone. Boreholes that reached the crystalline basement of the Westmorland Uplift (Fig. 6) sampled granites, mafic plutonic rocks, schist, and marbles — all rocks characteristic of the Brookville terrane described earlier under ***Pre-Late Devonian Crystalline Basement***. Those rock types also dominate the clast population of the Steeves Mills conglomerates and sandstones.

Depositional Environment: The Steeves Mills Formation is not exposed on surface, which prevents obtaining information about bedforms and sedimentary structures. However, the cyclicity of conglomerate, sandstone, and mudstone in intervals that are metres to decimetres in thickness suggests the formation resulted from fluvial deposition. The mudstone intervals are predominantly red, indicating that interfluvial deposits were probably well drained. Beds of slightly kerogenous mudstone and associated grey micaceous sandstone in the eastern part of the formation are interpreted as transgressive lacustrine tongues related to the perennial lake(s) that dominated deposition of the Albert Formation. Thus, the entire Steeves Mills Formation in the western part, and the upper portion of the formation in the eastern part, of its distribution area may represent an alluvial fan, possibly a middle to lower fan, formed by braided or distributary streams. The lower portion of the formation in the eastern part of the area contains lacustrine tongues and accordingly records fluvial and lacustrine-margin depositional environments.

Age: Eight spore assemblages (Table 3) were obtained from Wells 172, 254, 328, 687, and 688. Data from the assemblages indicate that the age of the Steeves Mills Formation is middle Tournaisian, ranging from Zone 2 to Zone 3, probably Zone 2A to probably Zone 3A (Fig. 15; Dolby 2000a, 2005). Dolby's palynological results (compiled in St. Peter and Johnson 2009) support the lithostratigraphic evidence of partial temporal equivalency of the Steeves Mills and Albert formations.

Relationship to Previous Stratigraphy: In the Berryton area, Gussow (1953) assigned the rocks above the Albert Formation to the Weldon Formation. On the western side of the Stoney Creek Field, he interpreted the coarse redbeds as Hillsborough Formation. Foley (1989) followed Gussow's lead and also logged the red and grey, coarse and fine interbedded strata above the Albert Formation west of the Stoney Creek Field as Hillsborough Formation. Foley's cross-sections showed the boundary between the Albert Formation and his Hillsborough Formation and provided a close approximation of what is now delineated as the Albert–Steeves Mills boundary, where the Steeves Mills is considered to be as defined herein. St. Peter (1992) mapped the rocks assigned herein to the Steeves Mills Formation as a coarse lithofacies of the Albert Formation.

Indian Mountain Formation

Author: St. Peter (2006a).

Type Section: St. Peter (2006a) introduced the name 'Indian Mountain Formation' for the section intermittently exposed along the unnamed brook that flows southward into North River southeast of Indian Mountain (Fig. 10). The brook is referred to informally as 'Indian Mountain Brook' in Park and St. Peter (2009) and herein. Indian Mountain, the stream, and the type section are situated in Westmorland County in map quadrant NST 21 I/02 (Plate 3; Fig. 10).

Definition and Description: The Indian Mountain Formation is a late early Tournaisian sequence of green to red fluvial strata conformably overlying the Albert Formation in the Indian Mountain Deformed Zone. The contact of the Indian Mountain Formation with the underlying Albert Formation is exposed in the Maple Glen Road quarry on the east side of 'Indian Mountain Brook' (Fig. 10; Park and St. Peter 2009). In that quarry and in an abandoned pit on the west side of the brook, the lowest beds of the Indian Mountain Formation are olive green to buff, pebbly to medium-grained sandstones with interbeds of fine-grained rippled sandstone and minor beds of mudstone and shale. The sandstone beds locally have prolific plant fragments, including *Sigillaria*. Small outcrops along 'Indian Mountain Brook' south of the quarry show the olive sandstones that characterize the lower part of the formation giving way upsection to reddish brown, mainly fine-grained sandstones with interbedded reddish brown mudstones (St. Peter 2006a; Park and St. Peter 2009).

About 6 km northeast of the Maple Glen Road quarry just south of McQuade (Fig. 10), the uppermost beds of the Albert Formation and the lowermost beds of the Indian Mountain Formation are exposed in the stream channel and along the banks of a tributary of Shediac River (Fig. 10). The following description is from Park and St. Peter (2009). The section of Indian Mountain Formation immediately above the organic mudrocks and sandstones of the Albert Formation along the tributary comprises three intervals that have an aggregate thickness of approximately 65 m. These intervals are as follows.

- Interval 1: At the base is about 40 m of stacked, fining-upward cycles. Each cycle is up to 2 m thick and comprises reddish brown, medium- to coarse-grained, massive to trough cross-bedded sandstone; thin reddish brown beds of fine-grained, rippled sandstone; and a cap of thin intervals of reddish brown to grey siltstone and mudstone.

- Interval 2: Above the fining-upward cycles is approximately 10 m of massive to very vaguely laminated, reddish brown, medium- to coarse-grained sandstone.

- Interval 3: The upper interval, about 15 m thick, is dominated by a lower unit of reddish brown, massive, polymictic, granular to small-pebble conglomerate that, near its top and at the limit of exposure, passes into reddish brown coarse sandstone and flaggy fine-grained sandstone and siltstone. The polymictic conglomerate is a highly unusual lithotype and is characterized by well-rounded (commonly tabular) intraformational or intrabasinal sedimentary clasts of fine-grained sandstone or siltstone. The clasts range from grey to purplish grey to yellow and rusty reddish brown. The yellow and reddish brown clasts may be sideritic or ankeritic. The clasts appear to be derived from lower beds of the Indian Mountain Formation, but some could be sourced from the sideritic and dolomitic siltstones of the Albert Formation.

About 5 km northeast of the above section, on the west side of Scotch Settlement Road, an analogous intraformational sedimentary clast conglomerate appears along the perimeter of a private pond at 46°13'0.7"N; 64°47'6.8"W (Plate 3). That conglomerate also contains multicoloured clasts of siltstone, ferruginous siltstone, ironstone, and fine-grained sandstone in a sideritic matrix (Fig. 20) and is located, as at Shediac River, a few metres or tens of metres above the contact with the Albert Formation.

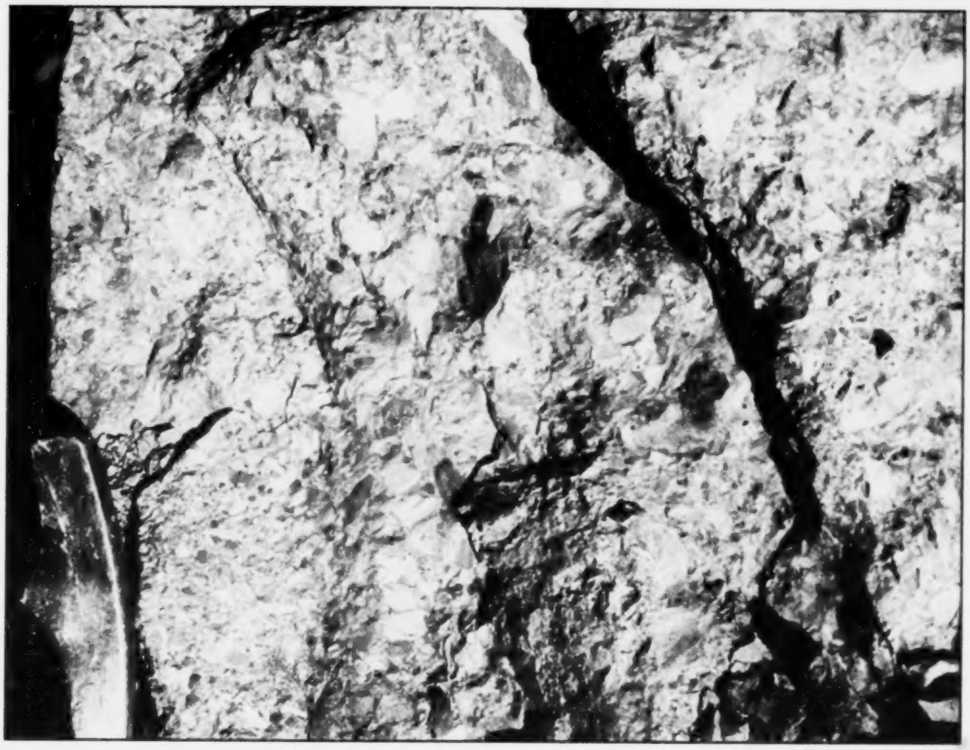


Figure 20. Polymictic conglomerate of the Indian Mountain Formation on the west side of Scotch Settlement Road, showing intraformational clasts of mudstone, siltstone, ferruginous siltstone, and fine-grained sandstone in a sideritic matrix.

Distribution and Thickness: The Indian Mountain Formation is geographically restricted to the Indian Mountain Deformed Zone, where it is exposed in a narrow belt on the north side of the North River Fault between Indian Mountain and Highway 115 (Fig. 6, 10). For 700 m to the south of the basal contact in the type section, the Indian Mountain Formation faces and dips steeply southward where it is cut off by the North River Fault. The exposures along 'Indian Mountain Brook' represent the thickest preserved section of the formation. If that section has not been disturbed by unidentified faults, it is approximately 600 m thick.

Lower and Upper Boundaries: In the Maple Glen Road quarry, the Albert Formation comprises black and grey kerogenous shale and siltstone with minor interbeds of grey to brown sandstone. The Albert rocks are overlain abruptly by the Indian Mountain strata, which show a cyclic repetition of fining-upward units of green, coarse, even pebbly sandstone to siltstone or shale (Park and St. Peter 2009). The upper part of the Indian Mountain Formation is cut out by the North River Fault. The formation's depositional boundary with the late Tournaisian Sussex Group is neither exposed on surface nor encountered in subsurface drillholes.

Lateral Facies Relationships: In the Indian Mountain Deformed Zone, the Indian Mountain Formation overlies the Albert Formation. However, in the subsurface of the eastern Moncton Subbasin, the Albert Formation is in part laterally equivalent to and overlain by the Steeves Mills Formation. Contact relationships and palynostratigraphic data suggest that the Indian Mountain and Steeves Mills formations must be at least in part temporally equivalent, if nowhere spatially adjacent.

Depositional Environment: The presence of repetitive fining-upward cycles of pebbly (locally cross-bedded) sandstone, rippled finer grained sandstone, siltstone, and mudstone indicate that, for the most part, the Indian Mountain Formation records fluvial deposition. The thick interval of sedimentary-pebble conglomerate exposed a few tens of metres above the base of the formation also shows a fining-upward trend to reddish brown coarse sandstone, flaggy fine-grained sandstone, and siltstone. This thick coarser interval, with its sideritic and ankeritic siltstone clasts, implies that in the adjacent upland the Indian Mountain fluvial system may have eroded (at least in part) the subjacent Albert Formation.

Age: Two samples of Indian Mountain Formation have provided lean palynological assemblages (Table 3). Although the assemblages are sparse, they show a general age of middle Tournaisian Zone 2 or 3 (Fig. 9, 15). This age supports the conclusion that the Indian Mountain Formation is depositionally continuous with the Albert Formation and predates the unconformity at the base of the Sussex Group.

Relationship to Previous Stratigraphy: The strata assigned herein to the Indian Mountain Formation were previously included in the Moncton Group by Norman (1941b; Gussow 1953; Carr 1968) and in the Moncton Formation by St. Peter (1989b). The names 'Moncton Group' and 'Moncton Formation' have been abandoned (see Park and St. Peter 2005; Hinds and St. Peter 2006; St. Peter 2006a).

SUSSEX GROUP

'Sussex Group' is a name introduced by St. Peter (2002) for a sequence of latest middle to late Tournaisian continental clastic rocks that unconformably overlie the Horton Group and unconformably or disconformably underlie the Windsor Group (Fig. 8, 9). In the report area the group comprises coarse-grained alluvial rocks of the Round Hill, Stilesville, Briggs Cross, and Ridge Brook formations, fine-grained grey alluvial–fluvial clastics and playa evaporites of the Gautreau Formation, fine-grained alluvial and fluvial redbeds of the Weldon Formation, and a thin ash unit, the Boyd Cr[eek Tuff.

The important unconformity that separates the Sussex Group from the Horton Group was first recognized during field mapping in the Sussex area by St. Peter (2002). It was previously predicted in that area by Corridor Resources Inc. on the basis of seismic reflection profiles and exploration wells in the McCully Field (Fig. 6). The company kindly shared its knowledge with St. Peter who, after field mapping in 2004 in the eastern Moncton Subbasin between Caledonia Mountain and Hillsborough, conclusively demonstrated the existence of the earlier documented unconformity in the Sussex area. Preliminary results of that work were published in Park and St. Peter (2005).

Prior to discovery of the unconformity, rocks above its surface were mapped as the upper part of the Albert Formation and the overlying Moncton Group by Evans and Alcock (1945), Alcock and MacKenzie (1946), and Gussow (1953). McCutcheon (1978) and St. Peter (1989b, his Plates 89-104F and 89-104G) assigned the same rocks to the upper part of the Albert Formation and the Weldon Formation. They considered those rocks to be concordant with the subjacent Albert Formation and therefore part of the Horton Group. Interestingly, the potential existence of a significant unconformity in the section in the eastern Moncton Subbasin had been suggested by Wright (1922, p. 16) at the base of his Weldon Series and by Norman (1941a) at the base of his Weldon Formation. All subsequent workers either ignored or failed to recognize the regional nature of that tectonic and erosional break. For example, since the seminal work of Gussow (1953) and his mapping colleagues at Shell Oil Company, the Weldon Formation has been defended as gradational and conformable with the Albert Formation!

In the eastern Moncton Subbasin (Fig. 6), the Sussex Group lies with nonconformity on basement rocks of the Caledonia Uplift (Norman 1941a; McLeod 1980) and with unconformity on the Horton Group. The group comprises coarse conglomerates and lithic sandstones of the Round Hill Formation (McLeod 1980), laterally adjacent grey mudrocks and evaporites of the Gautreau Formation (Norman 1932), and overlying and laterally gradational red mudrocks and minor sandstones of the Weldon Formation (Norman 1941a). A thin felsic ash, the Boyd Creek Tuff (St. Peter 1989b), is present in the lower part of the Weldon Formation.

Sussex rocks also lie nonconformably on older deformed granitoid basement rocks in the Indian Mountain Deformed Zone north of Moncton (Fig. 6, 10). The Sussex Group there includes two formations dominated by polymictic conglomerates and immature lithic sandstones: the basal Stilesville Formation and the upper Briggs Cross Formation. In the northeastern part of the IMDZ, conglomerates of the Stilesville and Briggs Cross are separated by an intervening unit of grey mudrocks, minor red mudrocks, and sandstones comprising the Gautreau Formation. Southwest of the report area, the Gautreau Formation, as in the eastern Moncton Subbasin, is succeeded by red mudrocks of the Weldon Formation.

In the Cocagne Subbasin (Fig. 6) north of the Indian Mountain Deformed Zone, the Sussex Group is defined by an undivided unit of red polymictic conglomerates, lithic sandstones, and minor mudstones of the Ridge Brook Formation.

Round Hill Formation

Author: McLeod (1980).

Type Section: McLeod (1980) designates the outcrops along Peck Creek from the crystalline basement north to the Gautreau Formation as the type section. The section is located about 7 km southwest of Hillsborough, Albert County (NTS 21 H/15; Plate 4), and is shown in detail in Park and St. Peter (2005, their Fig. 22).

Reference Section: The southern end of the section at Boudreau Village on the east side of Petitcodiac River, Westmorland County (NTS 21 H/15; Plate 4), is a well-exposed and eroded cliff, accessible at low tide.

Definition and Description: The Round Hill Formation is a late Tournaisian alluvial fan sequence of mostly grey to greenish grey and locally red, polymictic conglomerate, fine-grained to granular sandstone, minor grey and red mudstone, and rare limestone. The formation lies against the Caledonia Uplift along the southern side of the Moncton Subbasin where it rests unconformably on Caledonia basement and/or the Albert Formation. It fines toward the north away from the basement where it is coeval with a playa sequence of the Gautreau Formation.

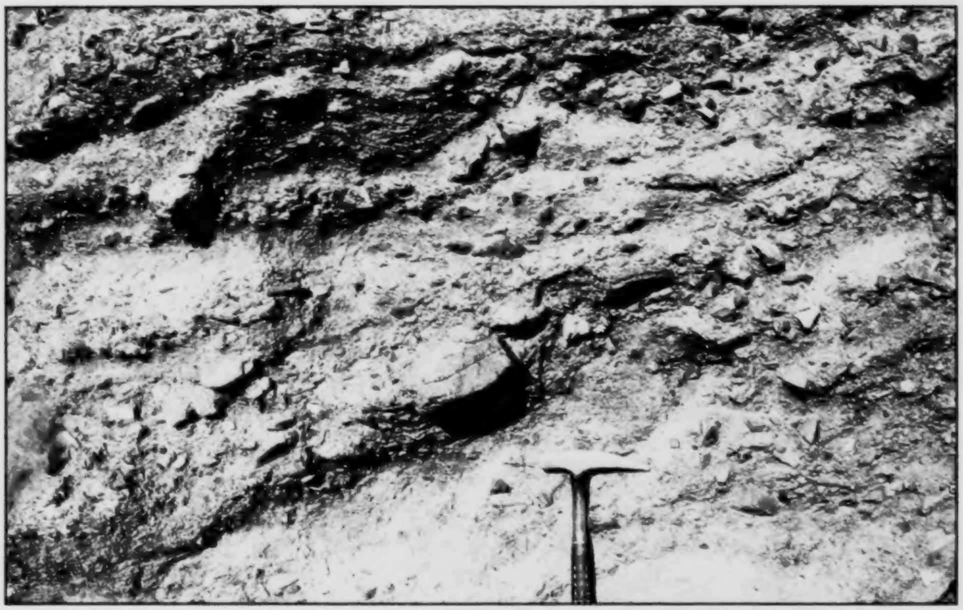


Figure 21. Greenish grey, poorly sorted, polymictic, pebble to cobble conglomerate of the Round Hill Formation on the east side of Petitcodiac River near Boudreau Village.

Conglomerate dominates the formation adjacent to the Caledonia Uplift. The conglomerate is grey or greenish grey in most exposures (Fig. 21); however, beds are locally red or reddish brown, as in the northern part of the section at Boudreau Village in the eastern Moncton Subbasin. The conglomerate occurs in beds 5 cm to 6 m thick, generally with sharp and erosive bases. Beds are typically massive and less commonly graded and range from horizontally stratified to lenticular. Cross-bedding is uncommon and is mainly small- to medium-scale and planar. Trough cross-beds occur locally in gritty conglomerates. Grading in the coarsest beds varies from boulder- to cobble-rich intervals near the base to pebble or grit zones at the top. Grading in the finer beds is shown by pebbly zones at the base grading upward to granular tops. Typical conglomerate exposures consist of horizontally interstratified tabular to lenticular beds of widely contrasting clast sizes. For example, very thick boulder- to cobble-rich beds occur together with pebble-dominated and granule-rich beds. Most of the conglomerate-dominated sequences fine upward. The tops of fining-upward sequences comprise sandstone and sandstone with mudstone interbeds.

The conglomerate is poorly sorted, with clasts in some beds ranging from fine-grained sand up to boulders 30 cm in diameter. The clasts vary from angular to well rounded. Grains of pebble size and larger are typically moderately well rounded to well rounded. In most cases the conglomerates have a clast-supported fabric. Imbricated clasts appear in rare cases of well-exposed horizontally stratified beds.

The following clasts were identified in outcrop and thin section: pink and purple rhyolite, schistose rhyolite, feldspar porphyry, quartz–feldspar porphyry, fine-grained granite, pink coarse-grained granite, biotite granite, mafic volcanic, schistose mafic volcanic, sericitic phyllite, sericite schist, quartz–muscovite schist, diabasic gabbro, ophitic gabbro, schistose gabbro, sandstone, conglomerate, quartz, feldspar, muscovite, and biotite. The detritus is dominated by felsic volcanic and metasedimentary rocks. The siliciclastic grains are analogous to bedrock lithotypes of the Avalon terrane in the Caledonia Uplift (Fig. 6; also see ***Pre-Late Devonian Crystalline Basement***, earlier). The matrix of the conglomerate comprises microscopically identifiable minerals including abundant chlorite and sparry calcite, and rare quartz and iron oxides. Dead oil or bitumen is locally present. Evidence of alteration of clast minerals is widespread. Plagioclase is typically partly or wholly replaced by calcite and white mica (smectite?). Ferromagnesium minerals and mafic volcanic grains are commonly altered to chlorite and lesser epidote (St. Peter 1992).

Sandstone is the most abundant minor lithotype in the Round Hill Formation. Where it occurs as interbeds within the conglomerate-dominated intervals, it typically forms lenticular beds that are generally less than 100 cm thick and pinch out over several metres. The lenticular character and varied bed thickness result from erosion at the base of overlying conglomerate beds. The sandstone beds range from massive to graded to cross bedded. The cross-beds are predominantly small-scale planar types. Sandstones in the section at Boudreau Village grade from pebbly at the base to medium grained at the top; the bases of the beds are sharp where they overlie mudstone.

The lithic arenites range from fine-grained to pebbly coarse-grained rocks; most are medium grained or coarser. The finer grained beds are typically moderately well sorted, whereas the coarser layers tend to be more poorly sorted. Sandstone beds of this type are compositionally indistinguishable from the matrix of interstratified conglomerates. The sand grains comprise significant quartz and feldspar and abundant rock fragments. Clasts are predominantly felsic volcanic and lesser mafic volcanic rocks, with minor mica schist and phyllite, quartz–mica schist, gabbro, and granite. The matrix of these sandstones comprises microspar and spar, chlorite, and fine-grained, optically unidentifiable clay minerals. Feldspars and rock fragments locally show extensive replacement by clay minerals (smectite and/or illite?) and calcite. Prior to void infilling, the sands had a (visually estimated) 3% to 10% intergranular and intragranular porosity. The pores are now filled with chlorite and carbonates with accessory iron oxides and bitumen (St. Peter 1992).

Mudstone and shale constitute a minor part of the conglomerate facies and occur as partings less than 1 cm wide between sandstone beds. Mudstone also appears locally in monolithological intervals up to and greater than 20 m thick. In most places, both mudstone and shale are dark grey or greenish grey. However, the mudstone tends to be red in sections where interbedded conglomerates are red. The mudstone strata are massive to parallel laminated, in which the laminae are composed of parallel or lenticular layers of silt and sand. Most beds contain slight to moderate amounts of calcite, and some contain granules of sand disseminated irregularly throughout. Locally, the muds have desiccation cracks and nodular limestone caliche. Where the mudstones are interstratified with coarse rocks, the upper contact of the mud beds is typically sharp or erosional, and the lower contact is either sharp or gradational with underlying sandstone.

A 25 cm thick limestone bed occurs in the conglomerate sequence, where the Round Hill Formation appears immediately north of the Edgetts Landing Fault on the east bank of Petitcodiac River at Boudreau Village (Park and St. Peter 2005, their Fig. 11b). The bed contains appreciable siliciclastic detritus in crystalline sparry cement and is overlain by angular-clast conglomerate (St. Peter 1992).

In the subsurface north of the Caledonia Uplift, the Round Hill Formation shows a gradual decrease in grain size from southwest to northeast. As in the exposed formation to the south, the section in Well 328 (depth interval 390–793 m) near Berryton is dominated by thick intervals of polymictic conglomerate with subordinate interbeds of greyish brown to reddish brown, fine to granular sandstone and rare reddish brown mudstone. In Well 705 about 1 km farther north, the formation (depth interval 624–696 m) is finer grained. It consists of mostly fine- to coarse-grained sandstone in intervals up to 15 m thick; pebble conglomerate beds up to 6 m thick are restricted to the lower part of the formation. The upper part of the unit contains reddish brown mudstone and what the company litholog describes as light grey to red-grey microcrystalline limestone — presumably calcrete. In Well 333 (depth interval 1521–1675 m; Fig. 14), which lies about 5 km southwest of Hillsborough, the formation is even finer grained. There, the formation reportedly comprises interbedded fine- to coarse-grained sandstone and mudstone with no conglomerate. Minor, very coarse sandstone occurs in the lower part of the section in Well 333. The interbeds of mudstone gradually change from dominantly grey in the lower part of the formation to mostly reddish brown in the upper part. Minor limestone associated with the mudstones is interpreted as calcrete. In the subsurface in Well 318 about 2 km southeast of Hillsborough, the same red conglomerates appear in the well as occur along strike from the section at Boudreau Village.

Distribution and Thickness: The formation is well exposed immediately north of the Caledonia Uplift along small tributaries of Peck Creek, along the north-draining tributaries of Weldon Creek, and at Round Hill about 1.5 km west of Peck Creek (Plate 4). Farther west, exposures of Round Hill rock occur along a tributary of Prosser Brook. On the east bank of Petitcodiac River near Boudreau Village in the Moncton Subbasin, a fault-bounded panel of Round Hill conglomerate forms a prominent headland between more recessive strata of the Albert Formation (Plate 4). The Round Hill Formation is also known from the subsurface in Wells 318, 328, 333, 698, 703, 705, and 706 (Plate 4).

The section of Round Hill Formation exposed along the north-flowing tributaries of Weldon Creek is about 250 m thick. This is a minimum thickness, because the lower part is cut out by the Caledonia Fault. A minimum thickness for the section at Prosser Brook is about 300 m; again, the section is juxtaposed against the basement along the Caledonia Fault. North of the basement in Well 328 near Berryton, the Round Hill has an estimated true thickness of 375 m but appears to thin sharply to the north. For example, in nearby Well 705 it is only about 70 m thick. In contrast, the overlying Weldon Formation increases abruptly in thickness from Well 328 to Well 705. The Round Hill Formation in the Boudreau Village section is cut by faults but exceeds 100 m thick. In Well 318, the base of the section is in fault contact with the Albert Formation, but the preserved section is greater than 200 m thick. Thus, the surface sections and well intersections of the Round Hill Formation demonstrate that the formation thins from south to north, away from the Caledonia Uplift (Fig. 14).

Lower and Upper Boundaries: The lower boundary of the Round Hill Formation is an angular unconformity or a disconformity. Norman (1941a) alluded to the presence of an unconformity at the formational base. He assigned the rocks placed herein in the Round Hill Formation to a coarse-grained informal member (his map unit 6a) of the Weldon Formation. His map legend notes that the section south of Weldon Creek has "a thick boulder conglomerate that overlaps onto pre-Carboniferous rocks [and] forms the base of the Weldon

Formation." McLeod (1980, his Plate 80-79A) mapped tiny outliers of Round Hill conglomerate lying on basement rocks south of the Caledonia Fault along Peck Creek. The unconformity of Round Hill resting on older Carboniferous rocks can be appreciated at the south end of the section at Boudreau Village. There, south of the Edgetts Landing Fault, tightly folded sandstones of the Albert Formation on the tidally washed exposures are overlain by gently dipping conglomerate of the Round Hill Formation. The conglomerate is exposed above the shoreline on the treed slope about 20 m above the Albert beds.

The unconformable Round Hill–Albert boundary was intersected in Well 703 at Edgetts Landing at a depth of 381.9 m. In the well, massive beds of reddish brown to green, polymictic pebble conglomerate with minor interbeds of medium- to very coarse-grained lithic sandstone lie abruptly on Albert mudstone. Typical grey Albert beds are reddened immediately below the unconformity for about 3 m, suggesting a weathered pedogenic interval. The first definitive microlaminated kerogenous shale of Albert affinity appears at the base of the weathered zone. Other evidence that the contact represents an exposure surface includes the presence of 1) tiny nodules of micrite overgrowing laminations in the mudrocks for 3 m below the base of the conglomerate, and 2) widely spaced 'veins' of calcite 1 mm to 3 mm thick and parallel to bedding laminations. The veins do not fill bedding-parallel shears but instead are displacive, propping laminations apart, suggesting the presence of a contemporaneous 'free space.'

The upper boundary of the Round Hill Formation with the overlying Weldon Formation is interpreted as conformable. Intermittent exposures across the contact appear along two small north-draining tributaries of Weldon Creek about midway between Caledonia Mountain and Peck Creek (Plate 4). The lithology there changes abruptly from the greenish grey conglomerates and grey to reddish brown sandstones of the coarse upper Round Hill Formation to the reddish brown, fine-grained sandstone and mudstone of the lower Weldon Formation. Bedding attitudes show no discordance across the contact. Exposures of Round Hill Formation at the Peck Creek type section indicate a fining-upward section concordantly overlain by interbedded grey and reddish brown mudrocks of the Gautreau Formation (Park and St. Peter 2005, their Fig. 22).

Lateral Facies Relationships: The Round Hill Formation is in large part a proximal temporal equivalent of the distal playa sequence represented by the Gautreau Formation (Fig. 14; also see ***Gautreau Formation,*** later). The Round Hill Formation lies unconformably on the Albert Formation along the southern margin of the Moncton Subbasin, whereas the Gautreau lies disconformably on the Albert around Weldon, the Stoney Creek Field (Fig. 13, 14), and lower Boyd Creek. Palynological data suggest, but do not prove, a lateral relationship between the formations.

The Round Hill Formation is also assumed to be in part a facies equivalent of the Weldon Formation. This is implied in the Berryton area where the Round Hill thins dramatically from 375 m in Well 328 to about 70 m in Well 705, whereas the Weldon Formation thickens from about 75 m in Well 328 to 190 m in Well 705. The northward increase in thickness of the Weldon Formation may have been even greater initially, as significantly more erosion took place at Well 705 than at Well 328 via the north-dipping unconformity at the base of the Hillsborough Formation. Borehole data demonstrate that the Round Hill is absent in the subsurface around Weldon; in contrast, the Weldon Formation there exceeds 1 km thick.

Depositional Environment: The Round Hill Formation has the external shape and internal facies architecture of an alluvial fan system (Bull 1972). The massive, poorly sorted conglomerates with clasts up to boulder size adjacent to the Caledonia Fault gradually give way to finer conglomerates and sandstones and, ultimately, sandstones with associated mudstones within 5 km of the Caledonia escarpment. The thickness data for the formation are fairly definitive and suggest it thins away from the Caledonia Uplift. Internally, the conglomerates and sandstones typically show cut-and-fill features, lenticular beds, and crude fining-upward cycles that indicate deposition mainly by braided streams (Williams and Rust 1969; Bull 1972; Mathews 1974; Miall 1978, 1985; Rust 1979, 1981; Reineck and Singh 1980; Rust and Koster 1984; McPherson et al. 1987). The conglomerates are largely grain-supported and have little mud matrix, which also suggests the deposits were largely waterlain (Williams and Rust 1969; Bull 1972; Rust 1979). Limestone interpreted as caliche is noted in logs for Wells 328 and 333. The caliche is associated mainly with mudrocks and suggests periods of minimal deposition and soil development on interfluves of the distal part of the fan complex.

Age: Eight spore assemblages (Table 3) have been retrieved from the Round Hill Formation: one from an outcrop at the Boudreau section and seven from Wells 333, 698, and 706. A profound degree of reworking of older Tournaisian Horton species occurs in almost all samples of the Sussex Group. This is particularly obvious in the Round Hill collections, where late Tournaisian (Zone 5) index species such as *Crassispora trychera* and *Schopfites claviger* are typically overwhelmed by middle Tournaisian Zones 2 and 3 forms such as *Umbonatisporites* (alternatively called *Dibolisporites*) *abstrusus*, *U. distinctus* and *Spelaeotriletes cabotii* (Fig. 15). For example, the Zone 2 age assigned to the three samples from Well 333 (spore locality AK on Plate 4) is certainly not the depositional age of the formation. The younger forms (*C. trychera* and *S. claviger*) occur in small numbers but cannot be dismissed as cavings contamination, because no potential grey pre-Sussex strata occur uphole to source those cavings (Dolby 1994). It should be noted that these two species have been interpreted to extend downward as far as Zone 3 of the middle Tournaisian in Nova Scotia (Utting et al. 1989).

Another example of reworking is in Well 698, where two Round Hill samples (spore locality AJ on Plate 4) occur at depths of 462.2 m and 473 m, immediately above the contact with the Albert Formation (Hiram Brook Member) at 473.4 m. The assemblage dates of Tournaisian Zones 1D to 2A (Dolby 2000a) are obviously not depositional ages but instead reflect ages typical of the Frederick Brook or Dawson Settlement members of the Albert Formation, which lie 200 m to 800 m deeper in the well. The age of middle to late Tournaisian Zones 3–4 (Dolby 2000b) interpreted for the sample from the Boudreau section (spore locality 54 on Plate 4) is thought to be closer to the depositional age of the Round Hill Formation.

Relationship to Previous Stratigraphy: Norman (1941a) and Gussow (1953) mapped the rocks assigned herein to the Round Hill Formation as a local, coarse-grained informal member of the Weldon Formation. McLeod in his original definition of the Round Hill Formation considered it as a facies equivalent to part and possibly all of the Albert Formation (McLeod 1980). His interpretation of the Round Hill being at least in part equivalent to the Albert was subsequently followed by Pickerill and Carter (1980), Pickerill et al. (1985), and St. Peter (1992). However, St. Peter later collected a sample from the conformably and immediately overlying Gautreau beds at Peck Creek; the sample assemblages yielded an age of late

Tournaisian Zone 5 (Dolby 2004). That date provided time proof that the Round Hill Formation could not possibly be a temporal equivalent to the early Tournaisian Albert Formation. Additionally, wells drilled in the late 1990s and early 2000s, interpretation of seismic reflection profiles, and the exhumed unconformity of Round Hill Formation sitting on Albert Formation at Boudreau Village, all provide lithostratigraphic evidence that the Round Hill Formation represents a younger deposition cycle than the older Horton Group (Albert Formation).

Stilesville Formation

Authors: Dr. Adrian Park of University of New Brunswick recommended the name 'Stilesville Formation' after conducting field work in the Indian Mountain area in 2005 for NBDNR. The name was subsequently used by St. Peter (2006a) for the basal, conglomerate-dominated unit of the Sussex Group in that area.

Type Section: The type section for the Stilesville Formation lies along the north side of the Moncton Crushed Stone quarry in The Gorge area, just south of Stilesville, Westmorland County (NTS 21 I/02; Plate 3; Fig. 10). The section is detailed in Park and St. Peter (2009).

Definition and Description: The Stilesville Formation is a basal unit of mainly locally derived coarse-grained redbeds (breccia and conglomerate) of the Sussex Group exposed in the Indian Mountain Deformed Zone (Fig. 6), where it lies nonconformably on crystalline basement. The late Tournaisian Stilesville is gradationally overlain by, and is interpreted to be laterally in part coeval with, the Gautreau Formation (described later).

The Stilesville Formation comprises reddish brown and greyish green, angular to subrounded, polymictic, granule to boulder breccia and conglomerate with varied quantities of extrabasinal clasts of granite, diorite, schist, and feldspar and intrabasinal clasts (from the Horton Group) of recycled conglomerate, sandstone, and siltstone. Greyish green breccia and megabreccia (regolith) with angular clasts and blocks of basement lithotypes up to several metres long appear adjacent to basement exposures. Massive breccia beds are commonly difficult to distinguish from the cataclastic basement granitoids from which they are derived. Reddish brown and greyish green, fine-grained to granular, lenticular-, parallel-, and rarely cross-bedded sandstone, minor reddish brown and grey siltstone and mudstone, and very rare silcrete, are minor components of the formation (Park and St. Peter 2009).

Some grey shale beds at the type section are typically rich in plant debris, whereas others have diverse trace fossil assemblages including *Cruziana problematica*, *Rusophycus carbonarius* and *Planolites* isp. (Pickerill 1992). Where preserved, the unconformity on crystalline basement is commonly a paleosol with phyllitic alteration extending down into the basement for 0.5 m to 3 m. Fissure fills of conglomerate reach into the basement from the unconformity for at least 50 m and are best observed in the Moncton Crushed Stone quarry at The Gorge (Fig. 10). Park and St. Peter (2009) provide further details on the geology at that quarry.

Exposures of the Stilesville Formation between the Dexter Construction quarry at Gorge Road and Lutes Mountain to the southwest (Fig. 10) reveal it as a fining-upward sequence. In the northeast and adjacent to the quarry, clast- and matrix-supported conglomerate beds several metres thick carry boulders nearly 1 m long. To the southwest and upsection, the

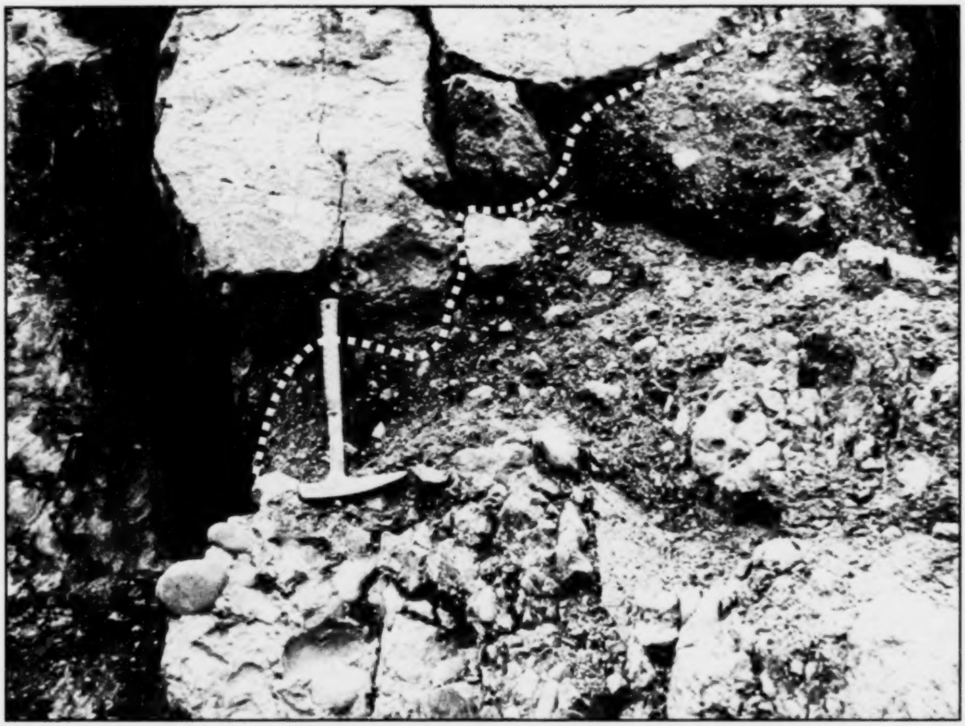


Figure 22. Huge boulder of highly indurated polymictic conglomerate (above dotted line) within a matrix of recessive and friable, polymictic, pebble to cobble conglomerate, megabreccia facies of the Stilesville Formation, McLaughlin Road quarry west of Irishtown.

conglomerate beds are thinner, and the clasts are mostly cobble and pebble size. Also, the upper part of the formation contains a greater quantity of sandstone beds.

In the western end of the McLaughlin Road quarry (Fig. 10), the Stilesville Formation reveals spectacular features, detailed in Park and St. Peter (2009). The conglomerate is megaconglomeratic with blocks of red, brown, and grey conglomerate, sandstone, siltstone and mudstone, some of which are 15 m in diameter (Fig. 22). The largest blocks are polylithic and retain the interbedded character and bedforms of their provenance formation. In some cases the finer grained sedimentary clasts have a fracture cleavage not present in the conglomeratic matrix, indicating that the clasts were lithified at the time of incorporation and therefore are not intraformational. The sedimentary clasts in the Stilesville Formation are indistinguishable from the interbedded lithotypes of the Memramcook Formation exposed in the central part of the quarry on the north side of an east-trending fault (Fig. 10; Plate 3).

The Stilesville conglomerate also carries extrabasinal clasts up to small boulder size of pink deformed granite, pink massive granite, rhyolite, purple feldspar–crystal tuff, green epidotized mafic volcanic rock, and green metasiltstone.

Distribution and Thickness: The Stilesville Formation is geographically restricted to the Indian Mountain Deformed Zone (Fig. 6, 10). It occurs proximal to the basement inliers at The Gorge and in fault-bounded blocks northeast of there to Irishtown, where it is juxtaposed against an inlier of Memramcook Formation at Shediac River. In The Gorge area, the Stilesville beds are well exposed in several quarries dug mainly in basement rocks. The massive conglomerates of the Stilesville are fairly indurated, resulting in numerous exposures in the forest-covered hills from The Gorge southwest to Magnetic Hill and northeast to Highway 490.

The thickness of the Stilesville Formation shows abrupt changes over restricted distances. Where the formation overlies the exhumed crystalline basement in The Gorge area, for instance, it is generally thin, ranging from a zero edge in some places to about 250 m at the type section on the north side of the Moncton Crushed Stone quarry (Fig. 10). In contrast, the section southwest of The Gorge toward Lutes Mountain is greater than 1300 m thick, assuming no repetitions by faults. This is a minimum thickness, because an unknown part of the section is omitted where the formation overrides the Gautreau Formation at The Gorge. Similarly, the preserved section between the McLaughlin Road quarry (Fig. 10) and the thrust fault that brings basement over the Stilesville Formation north of Ammon is estimated at about 1300 m. Again, this assumes the section is not internally duplicated by faults.

Lower and Upper Boundaries: In the quarries at The Gorge, the Stilesville lies either nonconformably on or in fault contact with highly deformed basement rocks (Fig. 10). The relationships exposed at the McLaughlin Road quarry suggest that, prior to faulting, the Stilesville also would have lain unconformably on the Memramcook Formation. The upper contact of the Stilesville with the Gautreau Formation is exposed at the type section on the north side of the Moncton Crushed Stone quarry (Fig. 10). The Stilesville fines upward over a few metres into greyish green shale of the Gautreau Formation. Similarly, on the northwest side of the Gray Stone quarry (Fig. 10) situated about 500 m south of the Moncton Crushed Stone quarry, the Stilesville Formation is conformably and gradationally overlain by reddish brown sandstone and mudstone of the Gautreau Formation. Further details are given in Park and St. Peter (2009, their Fig. 9 and Plate 1).

Lateral Facies Relationships: The thickness data cited above for the Stilesville Formation, and the interpretation of its depositional environment noted below, strongly indicate the formation was sourced from rocks of the closely subjacent crystalline basement and Horton Group. The formation is greater than 1 km thick immediately south or southeast of an implied escarpment along the basement and Memramcook inliers, suggesting the Stilesville becomes thinner and finer grained away from the source area in the subsurface to the south, southwest, and southeast. A roughly equivalent thickness of distal, fine-grained sandstones and mudrocks of the Gautreau Formation may also occur to the southwest or southeast (see ***Gautreau Formation,*** later). Thus, the proximal–distal pair of the Stilesville–Gautreau formations in the Indian Mountain Deformed Zone is analogous to the proximal–distal pair of the Round Hill–Gautreau formations that characterizes the southern flank of the Moncton Subbasin adjacent to the Caledonia Uplift (Park and St. Peter 2005; Park et al. 2007).

Depositional Environment: The aforementioned significant and abrupt variations in thickness suggest that the Stilesville strata were deposited on a substrate with apparently considerable relief. The thickness data imply the existence of a cryptic paleoescarpment with an approximately east–west trend where it lies just south of the present basement inliers at The Gorge. From there, the escarpment presumably turns north for, as noted above, a remnant of it occurs in the McLaughlin Road quarry where megabreccia of the Stilesville Formation is juxtaposed against the Memramcook Formation.

The generally coarse grain size and volume of detritus recorded by Stilesville rocks indicate that the formation had a local or proximal provenance. The huge size of the sedimentary blocks implies that the Stilesville beds in the west end of the McLaughlin Road quarry (Fig. 10) represent debris deposits formed very close to a paleoescarpment (Park and St. Peter 2009). The total area of the presently exposed crystalline basement at The Gorge and of the Memramcook Formation at Shediac River is not large enough to have produced the volume of detritus contained in the Stilesville Formation. It is not known whether the main source terrain was 1) a basement block that originally lay north of the North River Fault, or 2) the Westmorland Uplift, which is now buried by the Pictou Group on the east side of the Berry Mills Fault (Fig. 6). The presence of extrabasinal igneous detritus in the Briggs Cross Formation (see ***Briggs Cross Formation,*** later) strongly suggests that a local basement source area remained exposed and active in late Sussex time.

Age: Three datable palynomorph assemblages from grey mudrocks of the Stilesville Formation (Table 3) yield ages of latest middle to late Tournaisian Zones 3B to 5 (Fig. 15). Dates of Tournaisian Zone 2 or possibly Zone 3 from the Indian Mountain Formation, the youngest formation of the Horton Group in the area, indicate that the unconformity at the base of the Sussex Group is likely restricted to Tournaisian Zone 3 time and consequently represents a hiatus of limited duration (St. Peter 2006a; Park and St. Peter 2009).

Relationship to Previous Stratigraphy: The rocks assigned herein to the Stilesville Formation were ascribed to the Moncton Group (now abandoned) by Norman (1941b). Gussow (1953) placed the Stilesville beds in the Memramcook Formation (oldest Horton Group), presumably assuming they represented the basal formation of the Maritimes Basin succession because they lie on basement rocks. This assumption was repeated in much of the early work conducted on the Carboniferous rocks of New Brunswick without the aid of palynostratigraphy. The work has since proven to be more often wrong than right. Carr (1968) included a small part of the Stilesville Formation in the Albert Formation but mapped most of it as an unnamed boulder conglomerate unit interpreted to be laterally equivalent to the Memramcook Formation, Albert Formation, and Moncton Group. St. Peter (1989b, his Plates 89-104M and 89-104N) restricted the Stilesville Formation to a coarse facies of the Moncton Formation (now abandoned). Details of the structural geology of the Indian Mountain Deformed Zone had not been resolved by 2006 and, as a result, St. Peter (2006a) assigned most of the Stilesville beds to the younger conglomeratic Briggs Cross Formation. Recent structural work on the IMDZ (Park and St. Peter 2009) allowed this assignment to be rectified in the current report.

Gautreau Formation

Authors: Norman (1932), Greiner (1962).

Type Section: The type section for the Gautreau Formation is herein designated as depth interval 360 m to 928.4 m in Well 251 about 1 km east of Weldon, Albert County (NST 21 H/15; Plate 4). McCutcheon (1985) recommended Well 251, along with the nearby (15 m away) Well 364, as being a suitable amalgamated reference section for the Gautreau Formation. McCutcheon (1985) chose depth interval 360 m to 937.8 m in Well 251 and depth interval 387 m to 750.3 m in Well 364. The lower depth picked herein for the Well 251 type section is modified from 937.8 m to 928.4 m for the following reason: lithotypes that characterize the Albert Formation (e.g., grey calcareous sandstone, oil-stained sandstone, and black shale) appear below 928.4 m whereas typical Gautreau lithotypes (bluish grey shale, anhydrite, and glauberite) lie above that depth. A descriptive litholog of Well 251, including the Gautreau type section, is given in Hamilton (1961a). A textural and graphical log is available at NBDNR.

Reference Section: A reference section (see St. Peter 1992, his Fig. 22) is the cored interval between 265 m and 394 m in Well 366 immediately north of Weldon, Albert County (NTS 21 H/15, Plate 4). The core provides greater detail on the upper glauberite-bearing part of the Gautreau Formation and is stored at NBDNR.

Definition and Description: The Gautreau Formation is a late Tournaisian grey, fine-grained, fluvial clastic and playa lake evaporite sequence that overlies and is laterally transitional with the alluvial fan rocks of the Round Hill and Stilesville formations. It is gradationally overlain by fine-grained redbeds of the Weldon Formation. The following account describes the formation as documented in subsurface well intersections in the Moncton Subbasin, in surface exposures in the Moncton Subbasin, and in surface exposures in the Indian Mountain Deformed Zone (Fig. 6, 10).

Subsurface in Moncton Subbasin: Using the Gautreau type section in Well 251 as representative of the Gautreau Formation in the Weldon area, Hamilton (1961a) divided the formation there into two parts.

- The upper part, depth interval 360 m to 449 m, comprises shale (mudrocks) and minor associated glauberite, anhydrite, and gypsum. The shales and mudrocks immediately below the Weldon Formation boundary alternate over a depth interval of 15 m from grey to greyish green to reddish brown. Below 375 m the shales and mudrocks are entirely grey. Within the shales are local stringers, bands, and crystal masses of anhydrite and glauberite. Veins of fibrous gypsum and selenite are also present (Hamilton 1961a, p. 50–51). The section from 441 m to 443 m comprises massive glauberite with only minor laminae and beds of grey shale.

- The lower part, depth interval 449 m to 928.4 m, is dominantly (about 80%) rock salt (Hamilton 1961a, p. 51–56) but contains significant shale and rare glauberite and sandstone. The interbeds of grey shale appear throughout; the shale intervals are up to 7 m thick, but most are less than 1 m. Within the salt section are two intervals (580.8–582.3 m and 816.5–819.5 m) that contain abundant glauberite. The rock salt ranges from brown to red to white and translucent and typically carries inclusions of grey to black shale, contorted shale, and less commonly crystals of glauberite (Hamilton 1961a). The shale layers in the salt commonly contain salt crystals and glauberite crystals and are cut by salt veins.

St. Peter (1992) described what he called an evaporite lithofacies of the Albert Formation. That lithofacies is assigned herein to the Gautreau Formation. St. Peter (1992, his Fig. 22) used depth interval 260 m to 394 m in Well 366 as a reference section for the lithofacies. That section correlates roughly with the beds immediately above and below the rock salt boundary in Well 251. The following paragraphs summarize his description of that section.

The Gautreau mudstone beds are typically calcareous. Those in the medial part of the formation (i.e., those associated with rock salt and glauberite) are more accurately classified as carbonate mudstone, as they are composed dominantly of micrite. The mudstones that overlie the rock salt are salty. The degree of saltiness and thus the soluble salts content generally increases downsection from the Weldon–Gautreau contact to the first significant glauberite interval at 264.6 m. The soluble salts are too fine grained to detect with the unaided eye, but because halite and glauberite are the only significant soluble salts in the underlying evaporites, it is likely that one or both minerals account for the salty taste in the mudstones. Nodules and thin laminae of fine-grained gypsum crystals are also present in the salty mudstones.

At a depth below 301 m in Well 366, rock salt becomes the most abundant lithotype in the formation. The rock salt is typically coarse grained and ranges from pink to white to smoky grey. It occurs in beds less than 1 m thick up to intervals greater than 20 m thick. Beds of rock salt are rarely pure salt, as angular clasts of light to dark grey carbonate mudstone and thin beds of carbonate mudstone are commonly present. With an increase in the content of carbonate mudstone clasts, rock salt grades into mudstone breccia. In places, the clean rock salt and rock salt that form the breccia matrix contain minor amounts of dispersed glauberite crystals. Rarely, coarse glauberite crystals account for 50% or more of thin rock salt layers. Narrow veins of glauberite locally cut the salt.

Micritic carbonate mudstone is the most significant minor lithotype in the rock salt. It occurs in intervals ranging from a few centimetres to greater than 10 m thick. The mudstone is typically parallel laminated with colour laminae alternating from light grey to medium grey to dark grey, giving the rock an overall hue of dark grey. The mudstone also contains some light grey, parallel, siliciclastic silt to fine-grained sand laminae. Small-scale slump folds appear locally in the laminated mudstones. In thin section, mudstones display abundant evidence of desiccation. Mudcracks and sheetcracks (Smoot 1978) are common; both are typically filled with gypsum or glauberite.

Mudstone beds and mudstone intraclasts in the evaporites feature several postdepositional (diagenetic) minerals. Where glauberite beds are common, associated carbonate mudstones contain glauberite and gypsum crystals. The crystals show preferential growth along laminae but also display crystallization transverse to the laminae, attesting to their postdepositional origin. Rosettes of gypsum and glauberite, as well as randomly oriented porphyroblasts of gypsum and glauberite up to 2 cm in length, are common. Gypsum porphyroblasts have overgrown the nose of synsedimentary slump folds. This feature, along with the compactional drape of host rock laminae over gypsum and glauberite porphyroblasts, attests to the diagenetic origin of these minerals. Mudstone beds also locally contain diagenetic nodules of fine-grained gypsum and glauberite.

In the intervals dominated by rock salt, carbonate mudstone beds and mudstone clasts contain abundant halite crystals. The halite dissolved during thin section preparation, leaving only 'square' molds and scalloped-walled cavities to indicate its former presence. Nevertheless, the textural evidence strongly suggests a secondary (diagenetic?) origin for the halite where it occurs in mudstone beds.

Nearly all mudstone beds are pervasively cut by a network of secondary veins. The veins include coarse-grained halite, gypsum, and glauberite and feature cross-cut depositional and diagenetic textures. In places, where veins are abundant, mudstones grade into mudstone-clast breccias such as the halite–mudstone breccia described above.

Glauberite and glauberite-rich intervals up to 10 m thick occur in the upper and lower parts of the Gautreau Formation (Hamilton 1961a; St. Peter 1992). As with the associated rock salt, glauberite rarely appears as pure monomineralic beds. It typically contains minor to significant quantities (up to 50%) of angular carbonate mudstone intraclasts and thin mudstone interbeds. The presence of abundant glauberite crystals in mudstone beds and mudstone intraclasts shows that the mineral formed in the host mud matrix and did not precipitate from a standing body of water. Replacement of the host matrix was locally so complete that virtually pure glauberite layers resulted.

Surface Exposures in Moncton Subbasin: No surface exposures of the Gautreau evaporites have been mapped in the eastern Moncton Subbasin. However, the mudstone exposures along Boyd Creek contain 'salt hoppers' (Gussow 1953; Hamilton 1961a; Greiner 1962) that may be facies equivalents of the subsurface evaporites. Well data from the Stoney Creek Field and other exploration wells within several kilometres of Weldon and Pré-d'en-Haut (Plate 4) demonstrate that the subsurface evaporites are overlain, underlain (Hamilton 1961a), and laterally transitional with mudstones and minor fine-grained sandstones (St. Peter 1992). The mudstones and fine-grained sandstones characterize the Gautreau Formation in surface exposures. For example, Gautreau mudstones in the north end of the section at Boudreau Village show spectacular mudcracks and less commonly rainprints (Park and St. Peter 2005, their Fig. 14). Other evidence of aridity or seasonality includes diagenetic, precompaction, light grey, irregular, aphanitic limestone nodules or caliche. Rarely, such nodules are densely packed and coalesce to form thin limestone beds. In the Boudreau Village section, rare sandstone beds show parallel laminations in the lower part and wave-generated ripples in the upper part, suggesting initial current-generated transport and subsequent wave reworking (St. Peter 1992).

The Gautreau exposures north of the Saint-Joseph Fault in the Belliveau Village section (Fig. 23) are described by Park and St. Peter (2005). The grey mudrocks and shales there comprise a mass of sedimentary breccia across which minor folds show a reversal of vergence. The brecciated mass appears to have a tabular shape that lies parallel to the Saint-Joseph Fault and is interpreted as a solution collapse breccia originating from the rise of subsurface evaporites.

Surface Exposures in Indian Mountain Deformed Zone: In the Indian Mountain Deformed Zone, the name 'Gautreau Formation' was first applied by St. Peter (2006a) to the fine-grained strata between the conglomerate-dominated Stilesville and Briggs Cross formations. Gautreau beds are exposed in that area from the headwaters of Shediac River in the northeast to Pacific Junction in the southwest (Fig. 10) and from there are exposed continuously to Anagance Ridge, 45 km farther southwest (St. Peter 2006a). The grey mudstones that characterize surface exposures of the formation southwest of Pacific Junction are known from a borehole at Cornhill (Fig. 6) to contain rock salt and glauberite similar to that at Weldon (Carter and Pickerill 1985b).

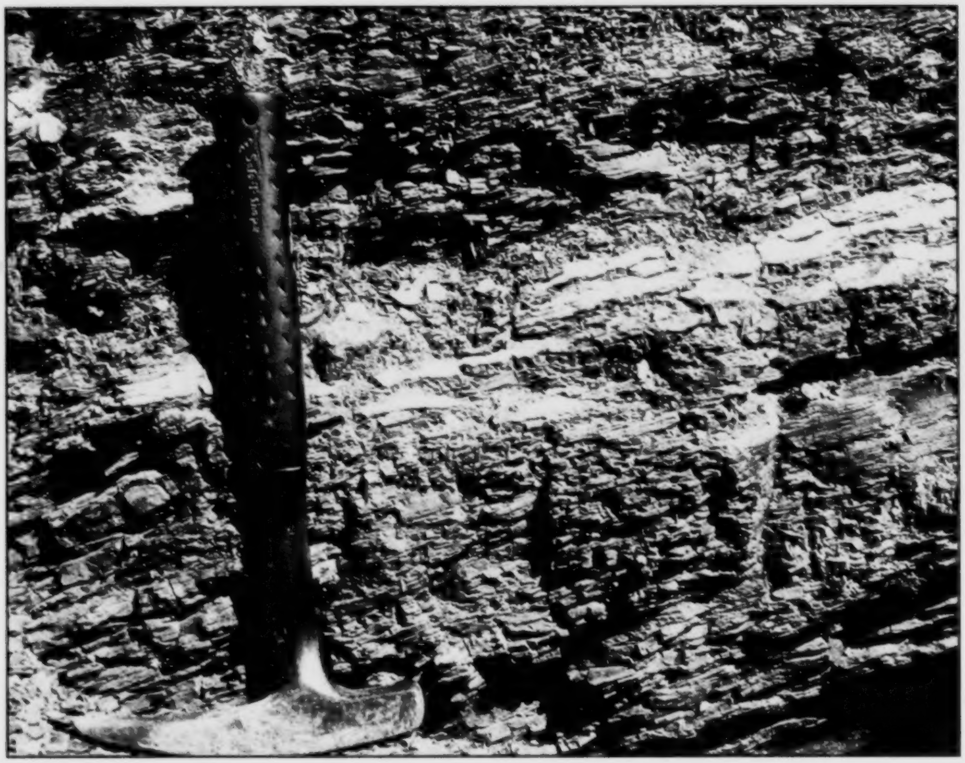


Figure 23. Grey mudstone and shale of the Gautreau Formation in a section along the east side of Petitcodiac River near Belliveau Village, north side of the Saint-Joseph Fault.

Between Pacific Junction and Shediac River, the formation comprises grey shale and mudstone or silty mudstone with lesser thin beds of fine- to medium-grained sandstone. In the northeastern part of the Indian Mountain area, the formation contains significant reddish brown shale and mudstone and also minor interbeds of coarse-grained sandstone and rare polymictic conglomerate. The grey and reddish brown mudrocks are typically calcareous and locally host calcrete nodules and rare nodular limestone beds (St. Peter 2006a). The lower part of the Gautreau Formation along Gorge Road comprises grey shales with minor interbeds of limestone and sandstone. They are succeeded by greyish green shales, also with sandstone and limestone interbeds, which in turn are overlain by green sandstone with shale partings. The fault-bounded slice of Gautreau Formation in the Dexter Construction quarry immediately east of The Gorge Road outcrops comprises well-sorted quartzose sandstone beds within dark grey shale. The sandstones in the quarry are grey, medium to coarse grained, slightly calcareous, and well indurated. The beds are 10 cm to 40 cm thick, vaguely graded, and unlaminated. Some beds contain fine carbonized plant debris.

The upper part of the Gautreau Formation is exposed in the Briggs Cross Road quarry on the north side of Briggs Cross Road (Fig. 10). The lower beds in the quarry section are mainly grey and comprise interbedded mudstones, shales, and very fine-grained to fine-grained sandstone. The mudrocks display mudcracks and locally rainprints. Interbeds of fine-grained sandstone have both current-generated cross-laminations and rare wave-generated symmetrical ripples. The upper beds in the section are largely reddish brown. The section coarsens upward toward the overlying Briggs Cross Formation, and coarser sandstone layers are more abundant toward the top of the section. The sands are up to coarse grained or pebbly and contain abundant pink granite or granitoid detritus, very similar to the granitoid basement exposed just northeast of there at The Gorge. Intraclasts of red mudstone are present at the base of some coarse sand beds. Complex polygonal sandstone dykes (?) locally cut interbeds of mudstone in the upper part of the section.

Rare thin beds of buff-weathering, grey limestone occur in the quarry section. Some of the limestone beds have a 'lumpy' texture, and others have parallel laminations of dark grey shale.

Distribution and Thickness: In the Moncton Subbasin, the Gautreau Formation is best known from the subsurface in the Weldon–Gautreau Village area, where it was intersected in mineral exploration drillholes and hydrocarbon exploration wells. That area spans both sides of Petitcodiac River. The best surface exposures of the formation in the subbasin are on the east side of Petitcodiac River at the north end of the Boudreau Village section. Other exposures east of the river occur near Gautreau Village along Boyd Creek and in the Belliveau Village section. On the west side of the river, the formation appears in outcrop on the north side of the Saint-Joseph Fault near Hillsborough. As well, isolated surface exposures are situated south of Isaiah Corner along Weldon Creek and Peck Creek.

In the Indian Mountain Deformed Zone, the Gautreau Formation lies between the Stilesville and Briggs Cross formations in faulted blocks from north of Ammon in the northeast to Pacific Junction in the southwest (Fig. 10).

The thickness of the formation in the subsurface in the Weldon–Gautreau area has not been well established. This in large part reflects difficulties on the part of previous workers in clearly defining a lithological boundary with the overlying Weldon and underlying Albert formations. Additionally, intraformational folds and contorted beds in the halite intervals and multiple zones of brecciated rock elsewhere in the formation have inhibited a confident assessment of thickness (Hamilton 1961a; St. Peter 1992). However, formational boundary picks with the Weldon Formation and Albert Formation in Well 251 yield a drill thickness of 586 m and in Well 247 a comparable 564 m. On the east side of Petitcodiac River in Well 229, just southwest of Gautreau Village, the Gautreau has a drill thickness of 448 m. Thus, the well data suggest the Gautreau Formation in the Weldon area has a true maximum thickness exceeding 500 m.

The well data also demonstrate that the formation thins away from the Weldon area and has a lenticular nature in the eastern Moncton Subbasin. In Well 333 just west of Hillsborough, the Gautreau lies between the Round Hill and Weldon formations and has a drill thickness of 190 m (Fig. 14). At Peck Creek to the southwest, grey to greyish green shale and interbedded reddish brown shale assigned to the Gautreau Formation lie concordantly above the Round Hill Formation and below the Weldon Formation in a unit probably less than 100 m thick (Park and St. Peter 2005; St. Peter 2006b). In the subsurface at Berryton even farther west, the formation is absent between the Round Hill and Weldon formations in Wells 328 and 705. The lenticular nature of the Gautreau Formation is also demonstrated by data from wells in the Stoney Creek Field (Fig. 13, 14).

The thickness of the Gautreau Formation in the Indian Mountain Deformed Zone (Fig. 10) was assessed by Park and St. Peter (2009). Just west of The Gorge, the formation is faulted against the Stilesville Formation and has a minimum thickness of 275 m. About 2.5 km southwest of The Gorge between Magnetic Hill and Lutes Mountain, the formation is approximately 500 m thick. About 12 km southwest of Pacific Junction, along North River, there may be up to 1500 m of Gautreau section (St. Peter 2006a). The formation thus shows a tenfold or greater increase in thickness between the exposed basement inliers at The Gorge and the North River area to the southwest (Fig. 10).

Lower and Upper Boundaries: The nature of the lower boundary of the Gautreau Formation with the underlying Round Hill Formation is exposed in the Moncton Subbasin at Peck Creek, where coarse conglomerates and grits of the Round Hill gradually fine upsection into interbedded grey and reddish brown mudstones of the Gautreau. The gradational boundary between the Round Hill and Gautreau formations is also apparent just west of Hillsborough in Well 333 (Fig. 14), where the contact is placed at 1521 m.

The Gautreau Formation sits on the Albert Formation in the subsurface in the eastern part of the Stoney Creek Field, in the subsurface around Weldon and Pré-d'en-Haut, and in adjacent updip outcrops. The boundary between the grey sandstones and dark grey to brown mudstones and kerogenous shales (Albert Formation), and the overlying grey mudstones with associated glauberite, anhydrite or gypsum (Gautreau Formation) has been a difficult contact for geologists to appreciate or recognize. Similarly, it has been challenging to agree on where to place the boundary in the various well records. Consequently, there has been a history of alternation and confusion among researchers, specifically about whether to include the Gautreau Formation in or separate it from the Albert Formation (cf. Norman 1932, 1941a; Gussow 1953; Greiner 1962, 1974; McLeod 1980; Carter and Pickerill 1985b; St. Peter 1992).

The main reason why the contact between the formations has been difficult to 'pick' from well records and in outcrop sections is that both units are dominated by fine-grained grey strata. The following contrasts between the Albert and Gautreau formations can be used to ascertain their boundary. The Albert commonly contains beds of sandstone that are micaceous and either grey or more typically brown and oil stained; the lower Gautreau Formation carries virtually no sandstone in the type area. The Albert Formation shales are typically dark grey to brown and nearly everywhere are dolomitic and kerogenous to some degree; the Gautreau shales and mudstones are typically lighter grey or even bluish grey, calcareous, and nowhere kerogenous. The Gautreau shales contain associated layers, intergrowths or veins of gypsum, anhydrite, and glauberite, minerals rarely if ever present in the Albert Formation. A palynostratigraphic break is apparent across the Albert–Gautreau boundary where it is fixed using the above criteria. Henderson (1940, p. 167) anticipated this possibility from the well data at the Stoney Creek Field when he wrote that the Gautreau lithotypes may "form a separate, later group lying unconformably upon the Albert shales."

In the Indian Mountain Deformed Zone, the basal contact of the Gautreau Formation is exposed on the north side of the Moncton Crushed Stone quarry (Fig. 10) at the type section of the Stilesville Formation. The Stilesville there fines upward over a few metres into greyish green shale of the Gautreau Formation. Similarly, on the northwest side of the nearby Gray Stone quarry, the Stilesville Formation, only a few metres thick at this location, is conformably and gradationally overlain by reddish brown sandstone and mudstone of the Gautreau Formation. West of the Gray Stone quarry along its access road from Gorge Road, the Gautreau Formation at different points along its basal contact lies on basement granitoids or on a thin, condensed interval of feldspar-rich conglomerate of the Stilesville Formation (Fig. 10).

In the eastern Moncton Subbasin, the upper contact of the Gautreau Formation shows a gradational relationship with the overlying Weldon Formation. Typically, the grey to greyish green shales that characterize the upper part of the Gautreau gradually become interbedded upsection with reddish brown shales or mudstones. The zone of interbedded grey and red strata is arbitrarily assigned to the Gautreau Formation; the boundary is therefore placed at the base of the first massive and thick red mudstone interval or where red rock becomes dominant upon ascending the section. This choice of boundary does not necessitate excluding thin intervals of grey to greyish green shale or mudstone from stratigraphic positions higher in the Weldon Formation, but it largely restricts the Weldon to a redbed unit. This definition of the Gautreau–Weldon contact has been used to assign the interbedded greyish green and reddish brown shales immediately above the Round Hill Formation at Peck Creek to the Gautreau rather than the Weldon Formation. For the same reason, the dominantly grey and lesser red mudstone interval at the north end of the Boudreau Village section is placed in the Gautreau Formation (Norman 1941a; Gussow 1953; McLeod 1980; St. Peter 1992).

Near Petitcodiac River where the Weldon Formation is eroded, the upturned beds of Gautreau Formation are unconformably overlain by the Hopewell Cape Formation of the Mabou Group (Plate 4).

In the Indian Mountain Deformed Zone, the upper boundary of the Gautreau Formation with the Briggs Cross Formation is exposed at the Briggs Cross type section on the south side of Briggs Cross Road, about 1 km west of Gorge Road (Fig. 10). There, red and greyish green mudstone and siltstone of the Gautreau Formation grade upward into sandstone, shale, and conglomerate of the Briggs Cross Formation (St. Peter 2006a; Park and St. Peter 2009). The lower beds in the Gautreau consist of red mudstone with lesser amounts of red siltstone and fine-grained sandstone, and with minor layers of green sandstone and greyish green shale rich in plant debris. Greenish coloration is more common toward the top of the Gautreau Formation in this section and continues upward into the pebble conglomerate, delineating the base of the Briggs Cross Formation. The Briggs Cross Formation is marked by sandstone and conglomerate units that gradually become coarser and thicker upward in the section.

On the south side of the North River Fault in the Indian Mountain Deformed Zone, the Gautreau Formation lies updip and largely southwest of the Stilesville Formation (Fig. 10). In turn the Briggs Cross Formation, disregarding the geometrical complications resulting from faults, is located updip and southwest of the Gautreau Formation. On a regional scale, the Sussex Group in that area thus faces southwest and dips off the basement and Memramcook inliers at The Gorge and Shediac River (Fig. 10).

Lateral Facies Relationships: The rock salt and associated evaporites of the Gautreau Formation in the Weldon area are interpreted as a saline lake (see below). The restricted lateral extent of the evaporites, as estimated from fairly close drillhole control, strongly indicate they laterally interfinger with adjacent mudstones and shales that are interpreted as an upland playa margin sequence (St. Peter 1992). (See ***Round Hill Formation***, earlier, for a discussion of the lateral facies relationship of the basement-bounding and proximal Round Hill Formation with the apparently temporally equivalent and distal Gautreau Formation.)

The regional variations in thickness described above for the Stilesville and Gautreau formations in the Indian Mountain area suggest that the thick coarse proximal Stilesville Formation, which occurs south of the cryptic escarpment that bounds the basement and Memramcook inliers, must give way to the southwest to a comparable thickness of distal fine-grained sandstones and mudrocks of the Gautreau Formation. In this regard, the proximal–distal pair of the Stilesville–Gautreau is analogous to the proximal–distal Round Hill–Gautreau pair that characterizes the southern flank of the Moncton Subbasin adjacent to the Caledonia Uplift (Park and St. Peter 2005; Park et al. 2007).

Depositional Environment: The greater than 400 m of rock salt in the Gautreau Formation at Weldon suggests a considerable period of evaporation. The lack of evidence of marine influence forces the conclusion that the evaporites represent a saline lake environment (Carter and Pickerill 1985b; St. Peter 1992). The evaporites and laterally adjacent clastic facies are analogous to those of present-day Death Valley or Saline Valley in California (Hardie et al. 1978). Supporting evidence of desiccation is offered by the prolific mudcracks in the laterally adjacent thick mudstone interval at the north end of the Boudreau Village section. Rare wave ripples in thin sandstone beds in the section suggest the presence of standing water, at least periodically.

The evaporite lithofacies contains micritic calcite, gypsum, glauberite, and halite. The first evaporite mineral to crystallize was micritic calcite, the host mineral in which the other minerals subsequently grew. The micrite forms carbonate mudstone beds containing thin parallel laminae of siliciclastic silt and fine-grained sand. The micrite shows uniformity and is observed to predate synsedimentary folds, features that together indicate an early, possibly primary origin. The generally arid and saline conditions inferred from desiccation features and associated salts almost certainly preclude a biogenic origin for the micrite.

The gypsum and glauberite have a diagenetic and epigenetic origin. No well-preserved depositional evidence can be observed to show that either mineral precipitated directly from a standing body of water. No colour bands or delicate parallel chemical laminae (varves) exist such as would be expected if the minerals had precipitated from a perennial saline lake (Hardie et al. 1978). Textural evidence supporting a diagenetic origin for the gypsum and glauberite includes the growth of porphyroblasts, nodules, and bedding-discordant layers replacing the host carbonate mudstones. Further evidence of early growth is shown by the compactional drape of micrite and siliciclastic laminae around sulphate porphyroblasts. The textural relationships suggest that the diagenetic gypsum and glauberite formed from saturated brines in the carbonate muds below the sediment–lacustrine water interface or perhaps on a playa mudflat–saline mudflat (Hardie et al. 1978) under arid conditions. Glauberite has been reported from saline mudflat sediments adjacent to a salt pan in the Saline Valley, California (Hardie et al. 1978).

The halite, like the gypsum and glauberite, is largely of diagenetic origin. It is intergrown with gypsum and glauberite and also appears as disseminated grains in the host mudstone.

However, most of the halite occurs as thick monomineralic intervals with widely distributed carbonate mudstone clasts. In all cases, the halite clearly postdates the host mudstone and accordingly is interpreted to be diagenetic.

To conclude this discussion of the Gautreau evaporites: micritic calcite and perhaps some halite are interpreted as primary saline lake deposits. The gypsum, glauberite, and most of the halite (as now seen) are of either diagenetic or epigenetic origin. The diagenetic phases most likely formed by evaporative pumping of groundwater and concomitant crystal growth in carbonate muds on desiccated mudflats bordering an ephemeral or perennial saline lake (St. Peter 1992). Carter and Pickerill (1985a, p. 81) interpreted the "evaporite suite as having formed in a shallow evaporitic lacustrine environment."

Excellent exposures of the Gautreau Formation occur in the Indian Mountain Deformed Zone along North River immediately west of Plate 3 and the report area. The beds there display multiple fining-upward sequences, each typically less than 1 m thick. The sequences consist of thin beds of grey, fine-grained, current-ripple-laminated sandstone overlain by thicker beds of parallel-laminated siltstone, which grade up into grey mudstone or fissile shale. The mudstones and shales locally show thin interbeds of diagenetic nodular limestone. Thin sections of these beds demonstrate that much of the present carbonate is secondary replacement of earlier diagenetic gypsum and possibly halite and shortite (Carter and Pickerill 1985b). Black carbonized plant detritus is abundant in some sandstone beds, and mudcracks are noted in some shale beds. Current ripples in the sandstone beds indicate a general southwest transport direction and are consistent with a low-energy fluvial depositional environment for the formation there. The predominance of mudrocks in the sequence suggests a distal alluvial plain. Carter and Pickerill (1985b) assign these beds to a shallow evaporitic lacustrine environment; however, the repeated presence of thin beds of current-rippled sandstone suggests fluvial transport, perhaps by means of sheetfloods, for the sandstone part of each cycle.

Age: A total of 56 spore assemblages are described for the Gautreau Formation: 18 from outcrops in the Indian Mountain Deformed Zone and 38 from outcrops and wells in the eastern Moncton Subbasin (Table 3). The age of the Gautreau Formation in the IMDZ is well constrained, and the assemblages reported by Dolby (1995b, 2004, 2006a) collectively indicate an age of late Tournaisian Zones 4–5 (Fig. 15). The assemblages examined before Dolby's work (by Barss 1963, *in* Carr 1968; and by McGregor 1983a) suggest a somewhat older Tournaisian age, one that most likely reflected the knowledge of palynomorph zonation available at the time. It is important to recall that those earlier palynological studies took place when the strata now assigned to the Gautreau Formation were considered to be either Horton Group (Albert Formation) or Moncton Group. Therefore, a lithostratigraphic bias probably existed in assigning the ages. The late Tournaisian ages reported by Dolby for the Indian Mountain area support the lithostratigraphic evidence that the Gautreau Formation lies above the Horton Group and is part of the Sussex Group.

Some samples in the eastern Moncton Subbasin are given early to middle Tournaisian ages by Dolby (1994, 2000b, 2005). Many of those samples are from well cuttings. Such assemblages (as discussed above under ***Round Hill Formation***) are typically dominated by middle Tournaisian Zone 2 or 3 species such as *Dibolisporites abstrusus* and *Spelaeotriletes cabotii*. These species are interpreted to be reworked from rocks of the older Horton Group (mainly Albert Formation). The typical occurrence in these assemblages of late Tournaisian forms such as *Crassispora trychera* and *Schopfites claviger* is interpreted to reflect the depositional age of the Gautreau beds, even though they appear in small quantities and were dismissed by Dolby in many cases as cavings contamination. Even if some late Tournaisian spores in the cuttings samples were from cavings, they would be from the conformably overlying Weldon Formation and so would still imply a late Tournaisian age for much of the Sussex Group.

The difficulty in assessing the depositional age of the Gautreau Formation from such data as isolated spore samples is exemplified by two adjacent samples at Peck Creek at localities 77 and 78 (Plate 4). Sample 77 yielded a rich assemblage dominated by *C. trychera* and thus provided a confident Tournaisian Zone 5 age (Dolby 2004). The adjacent sample 78 provided a rich assemblage dominated by simple Zones 2 and 3 species and only questionable *S. claviger* and *C. trychera* forms (Dolby 2006b). On the basis of the assemblage population, the assigned date for sample 78 was probably Zone 2 or 3 — a date that does not reflect the late Tournaisian depositional age of sample 77. Evidently, significant caution is required when interpreting the age of spore assemblages from the Sussex Group. Reworking of older Horton detritus is common if not ubiquitous.

Relationship to Previous Stratigraphy: The Gautreau Formation as defined herein is analogous to the 'Gautreau formation' of Norman (1932). Greiner (1962) applied the name 'Gautreau formation' in the sense of Norman (1932) for beds in the Weldon area but erroneously correlated and included the marine evaporites of the Windsor Group (Pugwash Mine Formation) in the subsurface at Dorchester. With the exception of Norman (1932) and Greiner (1962), all other workers in the area (Norman 1941a; Gussow 1953; Carr 1968; McLeod 1980; Carter 1985; Carter and Pickerill 1985b; St. Peter 1992, 1993) assigned the strata herein assigned to the Gautreau Formation to the Albert Formation.

Weldon Formation

Authors: Wright (1922), Norman (1941a).

Type Section: The Weldon Formation takes its name from Weldon Creek in Albert County (Plate 4), along which are numerous small exposures (Norman 1941a; Gussow 1953; McLeod 1980). Williams et al. (1985) specifies the type section as the exposures on Weldon Creek from its confluence with Frederick Brook to the mouth of Peck Creek and up Peck Creek for about 1 km (NTS 21 H/15; Plate 4).

Reference Sections: A good representative section of the formation appears in tidal cliffs on the east side of Petitcodiac River near Belliveau Village in Westmorland County (NTS 21 H/15; Plate 4). Shroder (1963, p. 44) also proposes a reference section along North River near Fawcett, which lies about 30 km southwest of Indian Mountain outside the report area.

Definition and Description: The Weldon Formation consists of mainly fine-grained, alluvial–fluvial redbeds with minor associated pedogenic carbonates. A felsic ash fall, the Boyd Creek Tuff, occurs locally in the lower part of the formation and is described separately later. The Weldon is late Tournaisian, possibly latest Tournaisian. It gradationally overlies both the

Round Hill and Gautreau formations and is unconformably succeeded by the Hillsborough Formation of the Visean Windsor Group. The most comprehensive description of the lithology of the Weldon Formation appears in Shroder (1963). (Note that, at the time of Shroder's work, the Weldon Formation and unconformably overlying Hillsborough Formation were assigned to the now-abandoned Moncton Group (St. Peter 1992). Some of the coarse-grained beds that Shroder (1963), Norman (1941a), and Gussow (1953) assigned to the Weldon Formation are placed herein in the Round Hill Formation.)

The Weldon Formation in the eastern Moncton Subbasin comprises mostly red mudstone, commonly with caliche nodules, minor sandstone, and rare conglomerate. Shroder (1963) described the Weldon Formation as being composed mainly of a hackly fractured red siltstone with minor amounts of interbedded shales, fine-grained sandstones, and siltstones. The siltstones are more appropriately classified as mudstones because of their generally muddy matrix. The mudstones contain laminae and thin beds of nodular limestone (caliche).

Characteristic features of the Weldon Formation are displayed in the section on the east side of Petitcodiac River near Belliveau Village (Plate 4; see Park and St. Peter 2005 for detailed section description). The lower, southern part of the section is dominated by reddish brown, massive, calcareous mudstone. Green reduction spheroids and green reduced zones along joints and shear surfaces are common. The mudstone beds have local, very thin to lenticular laminae of very fine-grained sandstone. Mudstones locally have small nodules of micrite and pseudomorphs of calcite after gypsum (?) crystals. The pseudomorphs are diamond or triangular in outline. Mudcracks rarely occur in the southern part of the section.

The sand content of the Weldon Formation increases somewhat in the central part of the Belliveau section from the Saint-Joseph Fault to the promontory or headland located about 500 m to the southeast. In this section, mudstone is again the dominant lithotype. The sand beds are typically light brown and range from very thin layers in the south to intervals up to 3 m thick in the north. The thinner beds are typically parallel laminated in the lower part and cross laminated in the upper part. Some beds are graded from medium-grained bases to very fine-grained tops. These beds have sharp or erosive bases. Very rarely are beds bioturbated. Dr. R. Pickerill (pers. comm. to CSP, 1991) identified the trace fossils *Cruziana problematica* and *Rusophycus carbonarius* from the base of a Weldon sandstone bed just north of the headland (Park and St. Peter 2005, their Fig. 17). In the same area, the mudstone beds in several places show mudcracks and layers of moderately well-developed carbonate nodules.

Along Peck Creek on the western side of Petitcodiac River (Plate 4), the lower beds of the Weldon Formation are mainly reddish brown mudstone with a few interbeds of olive grey sandstone (Fig. 24). The sand beds are typically thin but also appear in locally amalgamated intervals up to 6 m thick. The sand layers are characterized by parallel and current-generated cross-laminations. Desiccation cracks occur in the mudstones. The exposures along Peck Creek and on Weldon Creek adjacent to the Saint-Joseph and Salem faults are cut by many shears that are commonly demarcated by thin calcite veins and parallel green reduced zones.

Exposures of the Weldon Formation along Steeves Creek immediately above the Boyd Creek Tuff at Hillsborough were described by Shroder (1963) as the 'Steeves Creek Marlstone Member.' The section is about 70 m thick and comprises interbedded reddish brown to

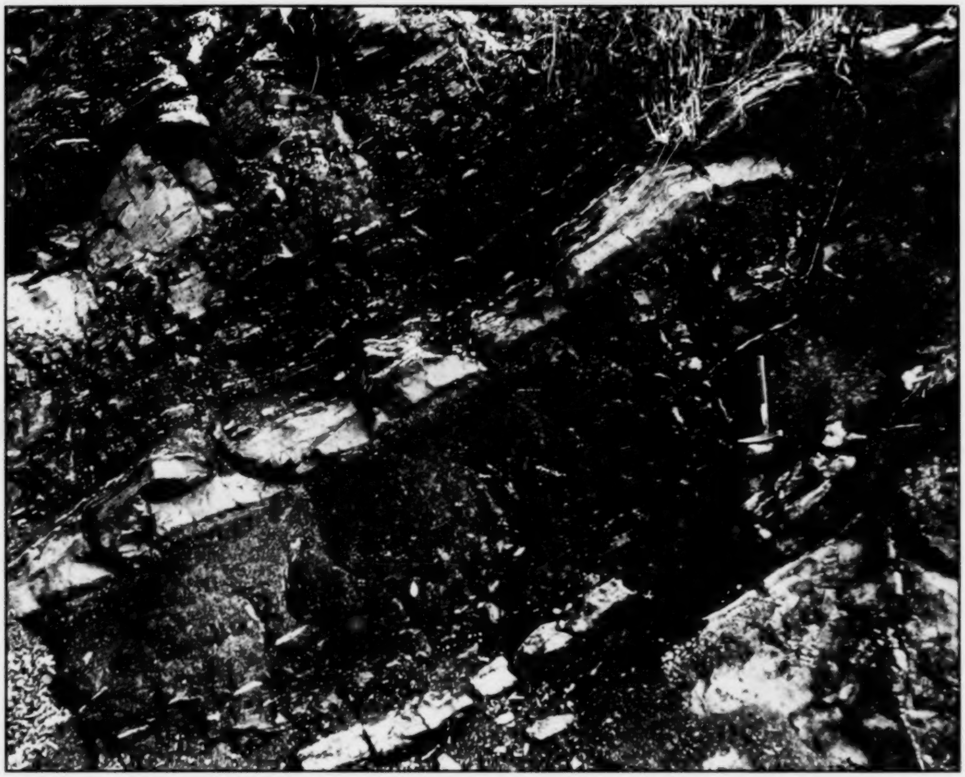


Figure 24. Reddish brown mudstone with interbeds of ripple- to parallel-laminated, fine- to medium-grained, olive grey sandstone of the Weldon Formation at Pecks Creek.

greyish green, marly limestone and limestone with lesser reddish brown siltstone and shale (Shroder 1963). Some of the limestone beds have jasper concretions and jasper-filled vugs and veins. The siltstone and shale beds locally contain micrite nodules.

The thickest currently known section of the Weldon Formation occurs in the subsurface just west of Hillsborough in Well 333, where it comprises a coarse interval immediately above and below the Boyd Creek Tuff. The upper and lower boundaries of the formation are at depths of 65 m and 1330 m; the intraformational tuff lies in depth interval 1075 m to 1090 m. The Weldon on either side of the tuff, between 935 m and 1180 m, contains approximately 60% sandstone in intervals up to 6 m thick. The company litholog describes the sandstones as grey to mainly rusty red, very fine-grained to granular, and rarely conglomeratic. They contain appreciable quartz, subordinate feldspar, and minor mica. The litholog also notes considerable limestone in the section above and below the tuff, suggesting a lithological correspondence to the abundant limestone recorded by Shroder (1963) in the section exposing the tuff on Steeves Creek.

(See ***Lower and Upper Boundaries***, below, for a short description of the Weldon Formation in the Indian Mountain Deformed Zone.)

Distribution and Thickness: The Weldon Formation in the report area is exposed in the eastern Moncton Subbasin from near the headwaters of Weldon Creek northeastward to Belliveau Village and Boyd Creek (Plate 4). It appears in well intersections on the south side of the Stoney Creek Field (Fig. 14) and in boreholes on the west side of Petitcodiac River between the Saint-Joseph and Edgetts Landing faults. It may occur in the subsurface in the Sackville and Cumberland subbasins (Fig. 9), but if present in the Sackville Subbasin, it was not intersected in Well 716 just northeast of Woodhurst. In the Indian Mountain Deformed Zone, the Weldon Formation crops out west of Pacific Junction beyond the report area and is continuously exposed southwest of there for about 60 km (St. Peter 2006a, his Fig. 4, 5).

The thickness of the Weldon Formation in the eastern Moncton Subbasin shows a remarkable variation. North of Caledonia Mountain at surface and in Well 353 about 3.5 km northeast of Rosevale, the Weldon is erosively cut out, and the Hillsborough Formation lies unconformably on the more steeply dipping Albert Formation. Northwest of there, in Well 328 near Berryton, the Weldon Formation (including the Boyd Creek Tuff) is unconformably succeeded by the Hillsborough Formation and has a drill thickness of about 90 m. From Well 328, the formation thickens to the north and in Well 705 (1 km north of Well 328) shows a drill intersection of approximately 200 m. In contrast, the thickness of the subjacent Round Hill Formation decreases dramatically from south to north between Wells 328 and 705.

The thickness of the Weldon Formation increases significantly east of Berryton. In Well 266 at Baltimore, the Weldon was intersected from the base of the Hillsborough Formation at 673 m down to the total depth at 1118 m, a drill thickness of 445 m. Farther east, in Well 333 southwest of Hillsborough, the Weldon overlies the Gautreau Formation at 1330 m and is overlain by the Hillsborough strata at a depth of 65 m, yielding a drill intersection of 1265 m (Fig. 14). North of Well 333 in the axis of the Weldon Syncline (see Plate 4, just west-southwest of Weldon), the Weldon Formation is even thicker and may exceed 1500 m thick (Fig. 14). East of Well 333, between Salem and Steeves Creek, outcrops of the Weldon Formation show a consistent northwest dip of about 60°, indicating a minimum true thickness of 900 m. In contrast, northeast of Well 333, the Weldon Formation rises toward the surface and is gradually cut out by the unconformity at the base of the Hillsborough Formation. For instance, the Weldon Formation (including the Boyd Creek Tuff) has a drill thickness of 221 m in Well 247 at Weldon. However, in Well 366 about 400 m to the northeast, the Boyd Creek Tuff is eroded and the remaining basal Weldon section only 100 m thick.

South of the Saint-Joseph Fault in Well 318 just south of Hillsborough, the Weldon conformably overlies the Round Hill Formation, is unconformably overlain by the Hillsborough Formation, and has a drill thickness of 142 m. About 4 km to the southwest in Well 695, the drill thickness of the Weldon between the Round Hill and Hillsborough formations is 238 m. Core-to-bedding angles in the Weldon average about 15° and suggest a formational thickness of approximately 230 m. In Well 696 (1.5 km north of Well 695), the same stratigraphy prevails and the Weldon has a drill thickness of 377 m. Core-to-bedding angles there show an average dip of about 60° for the Weldon Formation, implying a true thickness of about 190 m.

According to thickness data, the Weldon Formation is lenticular shaped with the thickest part of the lens in the area near Well 333 (Fig. 14). This contrasts with the Gautreau Formation, which is thickest northeast of there near Weldon. The lenticular shape of the Weldon Formation is in part controlled at its base and laterally by its facies relationship with the Round Hill and Gautreau formations and at its top by folding of and subsequent erosion by the Hillsborough and Hopewell Cape formations (Plate 4).

Lower and Upper Boundaries: Outcrop and borehole records indicate that the Weldon Formation in the eastern Moncton Subbasin gradationally overlies both the Round Hill and Gautreau formations (see ***Round Hill Formation*** and ***Gautreau Formation***, earlier).

In the Indian Mountain Deformed Zone, the contact between the Gautreau and Weldon formations is exposed along North River, about 2.5 km downriver from Pacific Junction, just beyond the western margin of Figure 10. There, grey, thinly interbedded mudstones and fissile shale and minor, graded, very thin-bedded sandstone of the Gautreau Formation are conformably succeeded by reddish brown mudstone and graded, thin-bedded, fine-grained wacke of the Weldon Formation (St. Peter 2006a). Mudcracks are present in both formations and, in the absence of other criteria, the basal Weldon boundary is placed at the base of the first reddish brown mudstone bed in that area.

The upper boundary of the Weldon Formation is an angular unconformity. This is evidenced in the Weldon area, where gently dipping strata of the Hillsborough Formation (Windsor Group) and subhorizontal beds of the Hopewell Cape Formation (Mabou Group) overlie moderately to steeply dipping beds of the Weldon Formation (Fig. 13, 14). The unconformities are manifested by the discordant strike of the younger formations relative to the underlying Weldon. Along the north side of Weldon Creek, for instance, the Hillsborough Formation gradually oversteps the Weldon Formation toward the west and ultimately lies on the Albert Formation at Rosevale. Further geological and seismic reflection evidence of the regional distribution of the basal Hillsborough unconformity is given in St. Peter (1992). The unconformity terminates sedimentation of the Sussex Group, recording a significant depositional break and tectonic event in the history of the Maritimes Basin (St. Peter 1993).

Lateral Facies Relationships: As noted earlier under ***Round Hill Formation***, the variations in thickness between the Round Hill and Weldon formations, and the different geographic or spatial relationships of those formations to the Caledonia basement (their apparent provenance), indicate they are at least in part a laterally equivalent proximal–distal pair. A similar argument applies to the relationship between the Weldon and Gautreau formations. For example, south of the Saint-Joseph Fault from Surrey to the headwaters of Weldon Creek, fairly close to the basement source, the Gautreau Formation is either thin or absent, whereas the preserved Weldon Formation beneath the basal Hillsborough unconformity is relatively thick (Fig. 14). In contrast, around the community of Weldon, farther from the Caledonia basement where the Gautreau contains a significant rock salt unit, the overlying Weldon Formation is relatively thin. Late Tournaisian palynological dates for the Round Hill, Gautreau, and Weldon formations (St. Peter and Johnson 2009) support the interpretation of the formations as lateral facies equivalents.

Depositional Environment: Shroder (1963) ascribes the interbedded mudrocks and current-ripple-laminated sandstones of the Weldon Formation to being the result of fluvial deposition. The mudstones and shales with caliche nodules and interbeds of nodular limestone have been variously interpreted as largely distal alluvial deposits and associated paleosols (Shroder 1963; St. Peter 1992) and overbank fluvial deposits (Carter and Pickerill 1985b). The predominance of very thick mudstones and lack of sandstone intervals suggest that channelized rivers were not a significant contributor to deposition. The lateral facies relationship between the coarse Round Hill Formation and the primarily fine-grained Weldon

Formation suggests that the Weldon resulted from deposition on the distal part of an alluvial fan or fans. The laterally related playa sequence represented by the Gautreau evaporites further supports that model. Under such a scenario, the coarse sandy interval associated with the Boyd Creek Tuff in Well 333 (Plate 4) must represent an anomalous distal tongue reaching out from the Round Hill fan.

Age: The oxidization that gave rise to the predominantly red Weldon strata hampers palynological dating of the formation, as oxidization commonly destroys any contained organic material. However, spores were recovered from three samples of Weldon grey mudrock: one from locality 79 in Well 256 and two from locality AT in Well 333 (Plate 4). All three samples provide a late Tournaisian age. As well, the deeper sample near the base of the formation at 1315 m to 1320 m in Well 333 gives a more definitive Zone 4 or 5 age (Dolby 1994). As noted earlier under ***Gautreau Formation***, the typical late Tournaisian zone markers *Crassispora trychera* and *Schopfites claviger* are commonly overwhelmed in the assemblages by 'reworked' early Tournaisian (Horton Group) species. However, those late Tournaisian palynomorphs must date the depositional age of their enclosing Weldon beds, because no younger beds appear uphole from which spore-bearing cuttings could have caved (see Dolby's 1994 comments *in* St. Peter and Johnson 2009).

Relationship to Previous Stratigraphy: The Weldon Formation as defined herein differs in part from the Weldon of previous workers. First, the coarse conglomerates along the crystalline basement from Caledonia Mountain to Peck Creek, assigned by Norman (1941a) to the Weldon Formation, are placed herein in the Round Hill Formation as per McLeod's (1980) recommendation. Second, the Boyd Creek Tuff lies in the lower part of the Weldon Formation. Stratigraphic and seismic reflection evidence supporting this interpretation has been reviewed by St. Peter (1992, 1993). Previous workers such as Gussow (1953) and Shroder (1963) placed the tuff at the base of the overlying Hillsborough Formation or in both the Weldon and Hillsborough formations (McLeod 1980).

A third point of clarification involves the earlier, differing definitions for the lithological content and boundaries of the Weldon Formation. Norman (1941a) introduced the name 'Weldon Formation' to describe the redbeds that he interpreted to overlie the Albert Formation. However, in that paper he changed his mind from Norman (1932) about placement of the evaporites and associated rocks that constitute the Gautreau Formation. On his Map 647A (Norman 1941a) of the Hillsborough area, he included the Gautreau evaporites in his Albert Formation and used the name 'Weldon Formation' for the redbeds that overlie the Gautreau Formation. Subsequent work has shown that the Weldon Formation is not conformable and gradational with the Albert Formation as argued by Norman (1941a), Gussow (1953), McLeod (1980), and St. Peter (1992, 1993). Instead, it lies gradationally above the Round Hill and Gautreau formations, both of which are either unconformable or disconformable on the Albert Formation. In fact, the Weldon is nowhere in depositional contact with the Albert Formation. Thus, 'Weldon' is used herein in the sense of Norman's 1932 paper or as defined in this report.

A final point requiring special attention here concerns the beds exposed along the lower part of Boyd Creek and their relationship to previous stratigraphy. Wright (1922) placed the beds from the top of his Albert Formation upsection to the south as far as Petitcodiac River in a sequence he called the 'Boyd Series.' His Boyd Series included the rocks assigned herein to 1) the Weldon Formation, 2) the Boyd Creek Tuff, and 3) the overlying coarse redbeds of the Hopewell Cape Formation (Plate 4). Wright (1922, p. 15) suspected his Boyd and Weldon series were one and the same but was unable to prove it. (Wright (1922) used the name 'Weldon Series' to include rocks that the current report places in the Round Hill and Weldon formations.)

In assessing the Boyd Creek section, Norman (1941a) placed the fine-grained redbeds and tuff that overlie the grey shales of the Gautreau Formation (his Albert Formation) in the Weldon Formation. However, he separated the overlying coarse redbeds that lie to the south and called them 'Hillsborough Formation.' Gussow (1953, his Fig. 5) and Shroder (1963) differed from Norman by assigning the tuff as a basal bed to the overlying coarse redbeds of the Hillsborough Formation. McLeod (1980, his Plate 80-78A) assigned all the rocks stratigraphically below the tuff to the Albert Formation. He mapped the tuff separately and, like Norman, Gussow, and Shroder, put the upper coarse redbeds in the Hillsborough Formation. St. Peter (1989b, his Plate 89-104A) mapped the coarse redbeds above the tuff as a coarse facies of the Moncton Formation (now abandoned) and later (St. Peter 1992, his Plate 92-34) as the Weldon Formation.

Evidence for including the Boyd Creek Tuff in the Weldon Formation is provided by St. Peter (1992) and is reviewed below under ***Boyd Creek Tuff***. However, the main concern here is assessing the stratigraphic position of the coarse redbeds above the Weldon Formation at Boyd Creek. Outcrop in the area is not sufficient to satisfactorily resolve the problem, but boreholes updip of the tuff outcrops provide a partial answer. Wells 226 and 229 cut the Boyd Creek Tuff, its enclosing fine-grained Weldon redbeds, and the problematic, sharply overlying coarse-grained redbeds. Well 320 lies between Wells 226, 229, and the tuff outcrops on Boyd Creek yet did not encounter the tuff (Plate 4). Instead, the coarse redbeds in Well 320 lie on red mudstones of the Weldon Formation at a depth of 177 m. Clasts of purple to purplish grey tuff occur in the coarse redbeds for at least 40 m above their basal contact and without doubt were eroded from the Boyd Creek Tuff. Thus, the coarse redbed unit is not depositionally continuous with the underlying Weldon Formation and so is not assignable to the Boyd Series or Weldon Formation as per Wright (1922) or St. Peter (1992).

The unconformity (disconformity) indicated by the tuff clasts in the coarse redbeds suggests that the coarse redbeds along the lower part of Boyd Creek and in the adjacent wells are assignable to either the Hillsborough Formation or the younger Hopewell Cape Formation, both of which occur locally. It is argued here that the coarse redbeds are more likely Hopewell Cape Formation than Hillsborough Formation. The mass of grey mudstone collapse breccia of the Gautreau Formation on the north side of the Saint-Joseph Fault in the Belliveau Village section is interpreted as evidence that the subjacent rock salt of the Gautreau rose near enough to surface to encounter fresh water. That upward rise may have been facilitated by movement on the Saint-Joseph Fault.

A similar rise of the salt is postulated as the cause for the anomalous absence and erosion of the Boyd Creek Tuff in the area near Well 320. When did the salt mobilize and influence the topography of the overlying stratigraphy? The Saint-Joseph Fault cuts the Hillsborough Formation west of Hillsborough yet appears not to have displaced the Hopewell Cape beds between Petitcodiac River and Saint-Joseph. Thus, if the fault had a role in raising the salt, it arguably occurred after Hillsborough deposition and before Hopewell Cape deposition. Therefore, erosion of the tuff and incorporation of its detritus in the coarse redbeds more likely occurred following elevation by the salt.

Given the foregoing reasoning, the redbeds are assigned to the Hopewell Cape Formation. Additionally, all previous workers have mapped the coarse redbeds on the higher topography east and west of Boyd Creek as the younger redbed sequence (Mabou Group or its previous name, the Hopewell Group). Consequently, there seems little justification in placing the coarse redbeds along the lower part of the creek in the older Hillsborough Formation. The interpretation offered herein restricts the Hillsborough Formation to the west side of Petitcodiac River (Plate 4).

Boyd Creek Tuff and Coeval (?) Dykes

Authors: Shroder (1963); revised by St. Peter (1989b) and St. Peter (1992).

Type Section: The type section is represented by exposures along Boyd Creek and its main east tributary, about 4 km north of Belliveau Village in Westmorland County (NTS 21 H/15; Plate 4).

Definition and Description: The Boyd Creek Tuff is a unit of felsic ash less than 35 m thick. It appears locally in the lower part of the late Tournaisian Weldon Formation (Sussex Group) in the eastern Moncton Subbasin. Shroder (1963) provides the most complete petrographic description.

The colour of the tuff is typically mottled purple, red, and cream (Fig. 25). The rock contains feldspar and quartz crystals from 0.1 mm to 0.3 mm in diameter as well as abundant accidental fragments (1 mm to several centimetres in length) of red shale and siltstone, and minor schistose mafic volcanic basement (Gussow 1953; Shroder 1963). Accessory minerals include garnet, magnetite, and hematite (Gussow 1953). The identifiable fragments and grains are set in a microcrystalline matrix of quartz and devitrified shards (Shroder 1963).

Distribution and Thickness: St. Peter (1992) describes the surface and subsurface distribution of the tuff in the eastern Moncton Subbasin using well logs and seismic reflection profiles. On the east side of Petitcodiac River, the tuff appears at its type section on Boyd Creek. In Well 226, which is located approximately 700 m north of the mouth of Boyd Creek, the tuff comprises two intervals of ash separated by 5 m of red and green marlstone. Wright (1922) likewise observes that the tuff on Boyd Creek occurs in two distinct 'beds' with an intervening layer of red and green shale.

The tuff has also been mapped on the west side of Petitcodiac River on Steeves Creek just north of Hillsborough. Shroder (1963) reports an exposure on a small creek 2 km north of Weldon and presumably on strike with the unit at Boyd Creek. Wright (1922) provides further details of possible surface locations in that area. The tuff was intersected in several boreholes in the Weldon Syncline on both sides of Petitcodiac River (Fig. 14; also see St. Peter 1992, his Plate 92-35). However, it has not yet been documented in outcrop or boreholes between

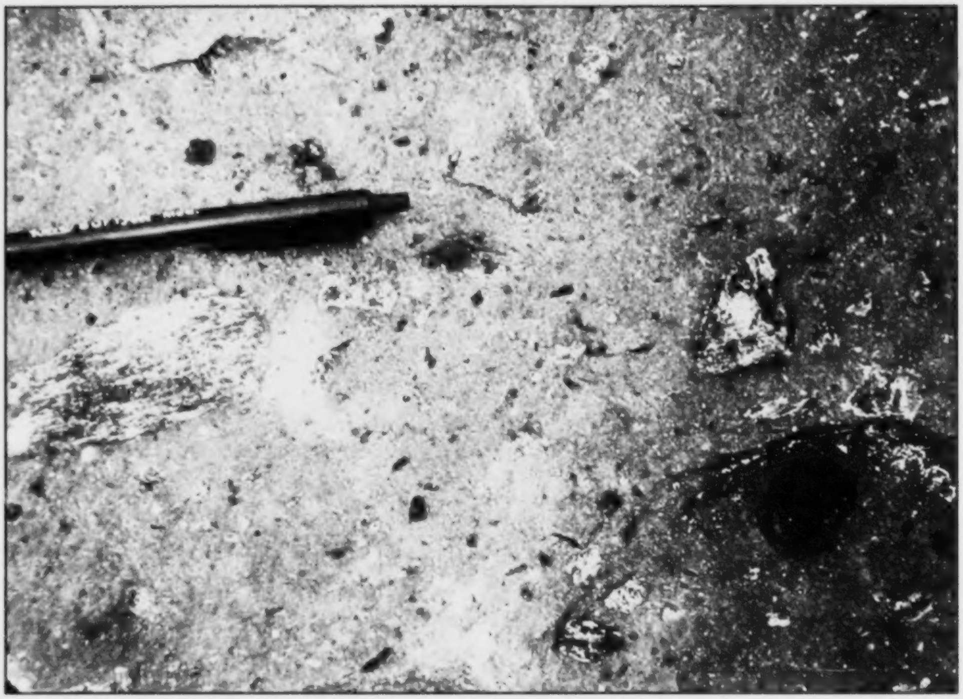


Figure 25. Mottled, pale purplish rock of the Boyd Creek Tuff at its type section on Boyd Creek. Tuff contains accidental lapilli of brownish red shale, siltstone, and multicoloured schistose mafic volcanic rock.

the Saint-Joseph Fault on the north and the Caledonia and Edgetts Landing faults on the south, despite the fact that the Weldon Formation is widely distributed in that structural panel. For example, the tuff is absent in Well 696, which is situated just south of the tuff's surface trace and south of the Saint-Joseph Fault (Fig. 14).

Well records indicate that the tuff decreases in thickness from east to west, as it is about 35 m thick north of Weldon but only 3 m thick in Well 328 just north of Berryton.

Lower and Upper Boundaries: Neither the lower nor upper boundary of the Boyd Creek Tuff is exposed in outcrop. Intersections of the tuff in many rotary-drilled wells in the Weldon Formation imply stratal concordancy.

Lateral Facies Relationships: Thickness data suggest the tuff may not have extended any significant distance west of Berryton. On the other hand, it is perplexing why the tuff appears to be absent south of the Saint-Joseph Fault, whereas it is 35 m thick just north of the fault near Weldon. Ash falls (see below) such as the Boyd Creek Tuff generally do not display abrupt changes in thickness over such a restricted area. At the same time, rocks of the Sussex Group are stratigraphically similar across the Saint-Joseph Fault, which appears to eliminate regional-scale lateral translation along the fault as a possible explanation for the tuff's absence south of the fault.

Depositional Environment: Shroder (1963) describes the tuff texture as comprising completely randomly oriented, accidental fragments without apparent evidence of flow alignment or welding. On the basis of those observations, he interprets the tuff as an ash fall deposit.

Age: The tuff lies within the Weldon Formation and therefore must be late Tournaisian in age.

Relationship to Previous Stratigraphy: Wright (1922) was the first geologist to recognize the tuff, mapping the two 'volcanic ash beds' at Boyd Creek as zones 2 and 4 of his Boyd Series. Norman (1941a) labelled the ash as map unit 6c of the Weldon Formation. Gussow (1953) interpreted the tuff as the basal unit of the unconformably overlying Hillsborough Formation on the assumption that it overlay a Weldon erosional surface. Shroder (1963) introduced the name 'Boyd Creek Ash' and followed Gussow, placing the tuff in the Hillsborough Formation. McLeod (1980, his Fig. 4) mapped the tuff as a separate entity but used it as a chronostratigraphic unit to interpret temporal equivalency of the Weldon and Hillsborough formations.

St. Peter (1989b, his Plate 89-104A) adapted the name 'Boyd Creek Tuff' from Shroder's (1963) 'Boyd Creek Ash.' St. Peter (1992) demonstrated that the tuff was concordant and folded with the Weldon Formation (Fig. 14) and thus did not lie at the base of the unconformably overlying Hillsborough Formation or share temporal equivalency with it.

Note: The Boyd Creek Tuff is not the only evidence of igneous activity in the Moncton Subbasin. Two northwest-trending felsic dykes on Peck Creek (Plate 4) intrude the Round Hill Formation and were first noted by McLeod (1980). The **Peck Creek Dykes** are each less than 1 m in width and are separated by about 3 m of sheared, greyish green sandy shale and sandstone. The dykes are light pink, fine-grained aplites. Apophyses of the dykes into their host clastics, clastic apophyses into the dykes, and lumps of the dyke material segregated from the main dyke mass and suspended in the bounding conglomerates are interpreted as evidence of intrusion into prelithification wet sediments (Park and St. Peter 2005). The dykes are younger than the Round Hill Formation and may be related to the same igneous event that generated the Boyd Creek Tuff. Park and St. Peter (2005) provide further details on textural features, interpreted mechanism of intrusion, and subsequent tectonic history of the dykes.

Briggs Cross Formation

Author: St. Peter (2006a), after a recommendation by Dr. Adrian Park.

Type Section: The type section of the formation lies about 1 km southwest of The Gorge, Westmorland County (NTS 21 I/02; Plate 3; Fig. 10), along the west ditch of a private road on the south side of Briggs Cross Road (St. Peter 2006a). The section lies immediately south of spore locality 63 on Plate 3.

Reference Section: A good reference section for the formation lies just west of the report area along North River, about 7 km southwest of Pacific Junction and immediately upsection from the underlying Gautreau Formation (St. Peter 2006a; Park and St. Peter 2009).

Definition and Description: The Briggs Cross Formation is the uppermost unit of the late Tournaisian Sussex Group exposed in the Indian Mountain Deformed Zone. It is a wedge-shaped alluvial fan and consists of mostly polymictic conglomerates and sandstones. The formation conformably overlies the Gautreau Formation, is interpreted to be laterally

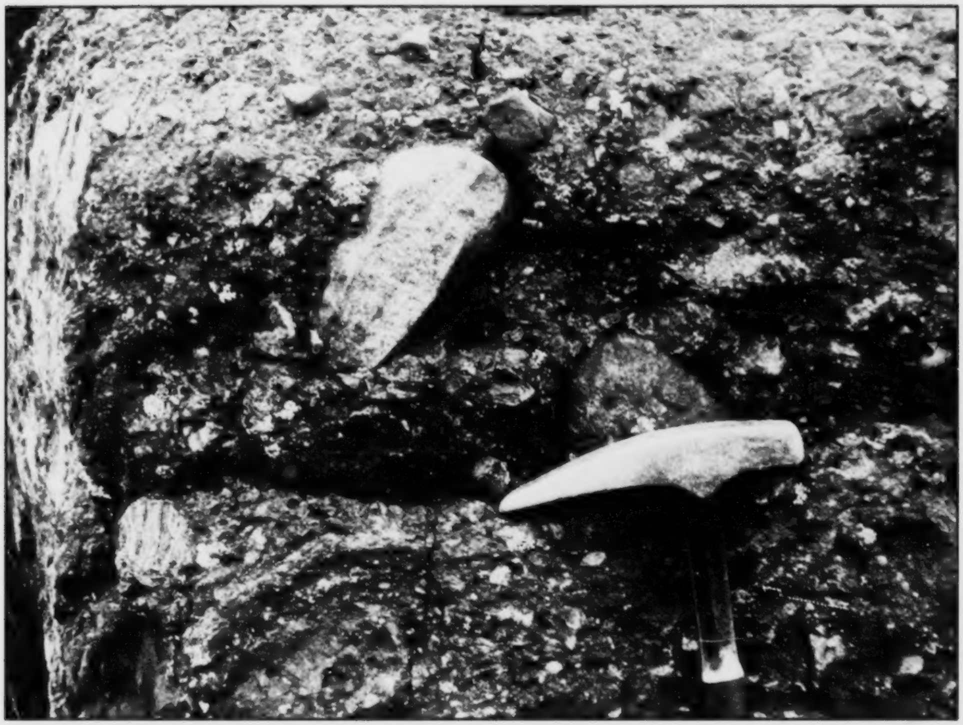


Figure 26. Polymictic, matrix-supported conglomerate of the Briggs Cross Formation in the Tri-Gil quarry at The Gorge. The rock contains pebbles and cobbles of mylonitic to cataclastic granite and recycled reddish brown Horton (?) sandstone.

coeval with the Weldon Formation, and in the report area is unconformably overlain by the Late Carboniferous Pictou Group.

The Briggs Cross Formation comprises predominantly coarse-grained redbeds. In a regional sense the Briggs Cross Formation comprises mostly reddish brown and rare greyish green, polymictic, granule to cobble, predominantly clast-supported conglomerate. The clasts range from subangular to rounded and comprise mylonitic and cataclastic granite, granite, diorite, schist, feldspar, and recycled reddish brown sandstone (Fig. 26), the last of which is interpreted to be from the Horton Group (St. Peter 2006a). Conglomerate beds in the northeasternmost exposures of the Briggs Cross Formation locally carry clasts as large as small boulders. The polymictic conglomerate beds commonly form the base of fining-upward, erosively based cycles that are 1 m to several metres thick. For example, along North River southwest of Pacific Junction, thick beds of conglomerate fill channels that are eroded 1.5 m deep into underlying flaggy sandstone. The conglomerates are either massive or trough cross bedded.

The conglomerate intervals are typically overlain by thin to medium, commonly lenticular beds of red to grey, poorly sorted, coarse-grained to granular lithic sandstones. Along North River, the coarse sandstones show horizontal and trough cross-bedding. The bases of the sandstone beds are generally gradational with underlying conglomerate, whereas the tops are either sharp or erosive where overlain by conglomerate. The coarse sandstones in some fining-upward cycles are succeeded by reddish brown, very fine-grained to medium-grained sandstone bearing either parallel laminations or current-ripple laminations. Intervals up to 3 m thick are present along North River where the beds form the upper part of channel sequences. The coarse lithotypes of the Briggs Cross Formation locally carry minor interbeds of reddish brown and grey siltstone and mudstone. Sandstone and mudstone on the north side of The Gorge Fault in the Tri-Gil quarry at The Gorge (Fig. 10) show evidence of synsedimentary foundering in the form of ball-and-pillow structures (Park and St. Peter 2009).

At the type section near The Gorge, sandstone, shale, and conglomerate of the Briggs Cross Formation gradationally overlie red mudstone and siltstone of the Gautreau Formation. The entire succession dips steeply and youngs to the south. The lower outcrops in the section are of the Gautreau Formation; they consist of red mudstone with lesser amounts of red siltstone and fine-grained sandstone, and minor layers of green sandstone and greyish green shale rich in plant debris. Green coloration is more common toward the top of the Gautreau Formation in the section; this continues upward into the pebble conglomerate delineating the base of the Briggs Cross Formation. The Briggs Cross is marked by sandstone and conglomerate that gradually become coarser and thicker upward in the section. The first units to appear are pebble conglomerate with vein quartz and granitic clasts. Within 25 m upsection, the succession is dominated by cobble conglomerate with more mixed clast populations, including recognizable sandstone of the Horton Group. In the lowest 10 m of the Briggs Cross Formation, red shale and green shale rich in plant debris persist. Higher up, the shale layers are generally grey with less visible plant debris.

Distribution and Thickness: In the report area the formation occurs in a triangular area with corners at The Gorge, Pacific Junction, and Steeves Mountain (Fig. 10). It occurs within three fault-bounded panels defined by the North River, Gorge, Salt Springs Brook, and Berry Mills faults. If the offsets on those faults were eliminated, the formation would lie regionally southwest and updip of the Gautreau Formation. The Briggs Cross Formation is exposed another 10 km southwest of Steeves Mountain, where it is overstepped by the Pictou Group. The formation thins in this area by a facies change with the underlying fine-grained Weldon Formation (St. Peter 2006a, his Fig. 5).

The total thickness of the Briggs Cross Formation cannot be determined because a complete unfaulted section does not exist. In the area of the type section near The Gorge, the preserved part of the section from its base to the Salt Springs Brook Fault is about 225 m thick. Southwest of The Gorge, in adjacent fault panels, an unknown thickness of the upper part of the formation is cut out by The Gorge and Salt Springs Brook faults. More section is preserved to the southwest: between North River and Steeves Mountain, for example (see St. Peter 2006a, his Fig. 5), the formation has an estimated minimum thickness of 800 m. However, 20 km farther southwest at Intervale, the Briggs Cross Formation has thinned to a zero edge (St. Peter 2006a).

Lower and Upper Boundaries: The lower boundary of the formation with the underlying Gautreau Formation is gradational at the type section. The gradational boundary between grey shales and sandstones of the Gautreau Formation and the overlying reddish brown sandstones and conglomerates of the Briggs Cross Formation is also exposed in the Dexter Construction quarry (Fig. 10) immediately below the thrust fault that carries the Stilesville Formation over the Gautreau shales and sandstones (Park and St. Peter 2009). At North

River south of Pacific Junction, the gradational contact zone is strongly indicated by the upward coarsening section of Briggs Cross Formation that lies immediately above the concealed boundary with the Gautreau Formation.

The exhumed Briggs Cross Formation in the report area is unconformably overlain by the Pictou Group near Berry Mills.

Lateral Facies Relationships: The contrasting data for regional variations in thickness of the Briggs Cross, Gautreau, and Weldon formations (see St. Peter 2006a) convincingly demonstrate that, before structural complications and ensuing erosion, the Briggs Cross Formation was a wedge-shaped body: thick in the northeast and thinning to the southwest. Supporting this interpretation is the fact that the grain size and quantity of conglomerate in the formation decreases toward the southwest. Commensurate with the decrease in thickness of the Briggs Cross Formation, the Weldon Formation and (less obviously) the Gautreau Formation increase in thickness toward the southwest. The basal boundary of the Briggs Cross is consistently gradational with either the Gautreau Formation (in the northeast) or the Weldon Formation (in the southwest). This observation, together with the opposing wedge shapes of the rock bodies, strongly suggests a lateral facies relationship between the coarse Briggs Cross Formation and the fine Gautreau and Weldon formations. Late Tournaisian palynological dates have been obtained from both the Briggs Cross (see below) and subjacent Gautreau (described earlier) — further supporting evidence of a lateral facies relationship.

Depositional Environment: The bedforms, traction structures, and dominance of coarse-grained lithotypes strongly suggest that the Briggs Cross Formation represents a proximal to medial alluvial fan complex comprising mainly waterlain braided stream deposits. The detrital content, which is dominated by granite and deformed plutonic rocks, is interpreted to have been shed from a crystalline basement such as that exposed at The Gorge. A provenance associated with basement in The Gorge area is supported by clast size, as well as the volume of conglomerate in the formation, which decreases from northeast to southwest. The wedge-shaped geometry of the Briggs Cross Formation between The Gorge and Intervale, 30 km to the southwest, also indicates a northeastern source area.

Age: Seven palynomorph-bearing samples have been recovered from the Briggs Cross Formation in the report area (Table 3). The samples at localities 80 and 81 along North River at Pacific Junction, and the three samples at locality AV (Plate 3) from grey shale beds on the north side of the Tri-Gil quarry near The Gorge, yielded late Tournaisian Zone 4 or 5 ages (Fig. 15; Dolby 1995b, 2006a). The dates are consistent with the lithostratigraphic position of the Briggs Cross Formation and are comparable with the late Tournaisian ages for the underlying Gautreau Formation. However, two assemblages from samples at locality AU (Plate 3) on the west side of the road south of Pacific Junction provided anomalous early Tournaisian ages (Carr 1968; Dolby 1991). The most plausible explanation is that the sparse assemblages in those samples represent reworked spores from older Horton strata and so do not yield the depositional age of the Briggs Cross Formation. The common occurrence of Horton sandstone clasts in Briggs Cross conglomerates is corroborative evidence of recycling and substantiates the existence of an unconformity between the Horton and Sussex groups (St. Peter 2006a).

Relationship to Previous Stratigraphy: Dr. Adrian Park recommended the name 'Briggs Cross Formation' while conducting field work for NBDNR in the Indian Mountain area in 2005. The name was subsequently used by St. Peter (2006a), who summarizes the nomenclatural history of the rocks placed here in the Briggs Cross Formation. The strata were assigned to the Albert Formation and Moncton Group by Stewart (1941a), to the Moncton Group by Norman (1941b), and to an unnamed boulder conglomerate unit interpreted as probably equivalent to the Horton and Moncton groups by Carr (1968). Gussow (1953) placed strata of the Briggs Cross Formation in three different groups: Horton (Memramcook Formation), Cumberland (Boss Point Formation), and Pictou (Salisbury Formation). St. Peter (1989b, his Plates 89-104M and 89-104N) allocated the Briggs Cross beds in the northeast to a coarse facies of the Moncton Formation and, like Gussow (1953), interpreted the strata southwest of Berry Mills as Pictou Group.

The stratigraphic position of this sequence has been long debated because 1) it consists nearly exclusively of coarse-grained redbeds and thus until recently has yielded no reliable spore assemblages, 2) its contact relationships with underlying and overlying rocks have been inadequately studied, 3) outcrop of the formation west and southwest of Berry Mills is very poor, and 4) the northeastern part of its distribution area is transected by numerous faults (Plate 3). The Briggs Cross Formation lies gradationally above the Gautreau Formation in the northeast and gradationally above the Weldon Formation in the southwest part of its distributional area. It is tempting to correlate it with the Hillsborough Formation of the Moncton Subbasin: it, like the Hillsborough, is a coarse redbed unit overlying the Weldon Formation. However, any such correlation is rejected here, because the Hillsborough, unlike the Briggs Cross, lies unconformably on the Weldon and older stratigraphy of the Sussex and Horton groups (Wright 1922; Gussow 1953; St. Peter 1992, 1993; Park and St. Peter 2005).

Ridge Brook Formation

Author: St. Peter (2006a).

Type Section: The type section lies outside the report area, 40 km west of Moncton along Ridge Brook north of Havelock in Westmorland–Kings counties (NTS 21 I/03; Fig. 6). It occurs just south of a crystalline basement inlier located along the Belleisle Fault (see St. Peter 2006a, his Fig. 4). The section, designated by St. Peter (2006a), includes exposures from the basement south to the first limestone beds of the Windsor Group north of Havelock (St. Peter 2006a). The Ridge Brook Formation adjacent to the basement dips gently southeast and otherwise shows little evidence of disruption by the Belleisle Fault. However, the formation is absent on the basement inlier on the north side of the fault, indicating a substantial magnitude of displacement between the basement and Ridge Brook Formation.

Definition and Description: The Ridge Brook Formation is a late Tournaisian polymictic conglomerate and sandstone-dominated sequence of alluvial–fluvial redbeds of the Sussex Group. In the report area the formation is restricted to the Cocagne Subbasin, where it abuts the northwestern edge of the Indian Mountain Deformed Zone (Fig. 6, 10; Park and St. Peter 2009); neither depositional contact is exposed in this area. At its type section along Ridge Brook north of Havelock (Fig. 6), the formation is in fault contact with early Paleozoic

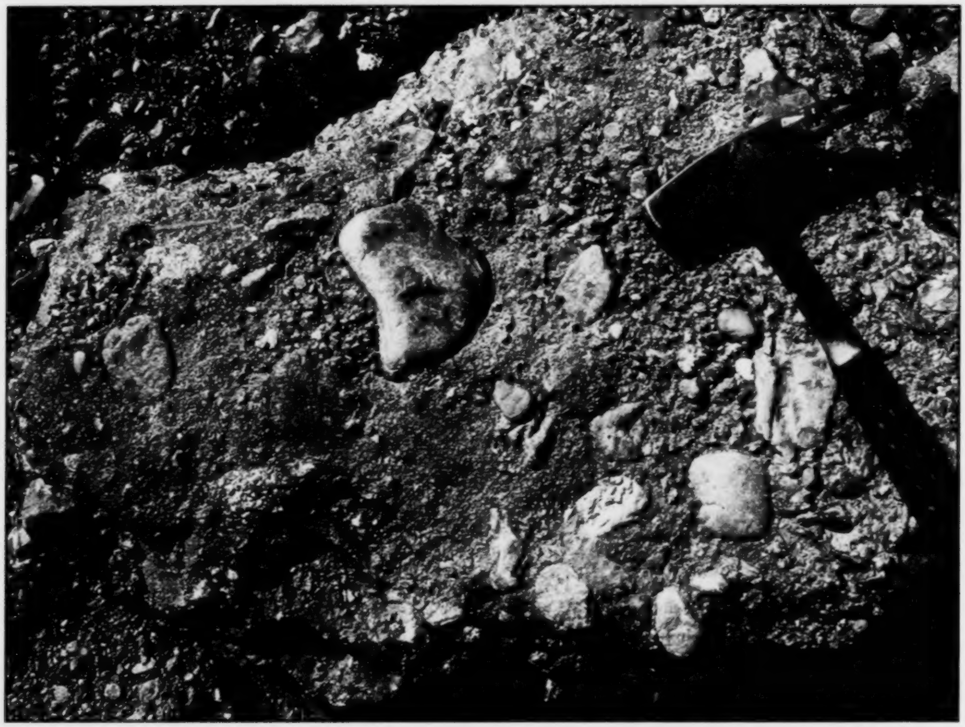


Figure 27. Reddish brown, matrix-supported conglomerate of the Ridge Brook Formation near Catamount, showing rounded pebbles of mainly dark grey metasedimentary rocks and subordinate pink granite.

metasedimentary rocks. At Havelock it is interpreted to be disconformably overlain by limestone of the Gays River Formation (basal Windsor Group; St. Peter 2006a).

St. Peter (2006a) describes the Ridge Brook Formation at its type section and elsewhere in the Cocagne Subbasin. The only exposures of the formation in the report area appear in the Catamount Road quarry (Fig. 10). The rocks in the quarry comprise reddish brown, polymictic, granule to cobble conglomerate interbedded with lesser medium- to coarse-grained lithic sandstone (Fig. 27). The beds are typically greater than 30 cm thick, and most are lenticular. Pebbles and cobbles are mainly well rounded. Rare outsized boulders of granite up to 40 cm in diameter are present. The conglomerate varies from clast- to matrix-supported, and the matrix is compositionally indistinguishable from that of the interbedded sandstones. Clasts in the conglomerate comprise green to brown quartzite, medium to dark grey metasiltstone, feldspar porphyry, medium-grained biotite granite, minor intermediate plutonic rocks, biotite schist, gabbro, muscovite granite, and vein quartz. The clast content of the Ridge Brook Formation contrasts sharply with that of the granite- and granitoid-rich detritus in the Stilesville and Briggs Cross formations. This contrast in clast composition and the demonstrable south-directed transport of detritus in the type section are the primary reasons for assigning the Ridge Brook separate formational status (St. Peter 2006a).

Distribution and Thickness: In the report area the Ridge Brook Formation appears in a triangular area between the Smith Creek and Springhill faults northwest of Catamount on the western edge of Plate 3 in the Cocagne Subbasin (Park and St. Peter 2009). It is exposed continuously from the Catamount area for 80 km southwestward within the Cocagne Subbasin (see St. Peter 2006a, his Fig. 4, 5) nearly to the Kingston Uplift (Fig. 6). The part of the formation exposed in the type section at Ridge Brook is about 600 m thick. It is not known how much additional section may lie below the exposed beds on the southeast side of the Belleisle Fault.

Lower and Upper Boundaries: The lower and upper depositional boundaries of the formation are not exposed in the type section at Ridge Brook or in the report area. The formation is faulted against basement rocks at the type section north of Havelock and rests unconformably on basement at Jordan Mountain (Fig. 6), 20 km southwest of Havelock (St. Peter 2006a).

Basal carbonates of the Windsor Group overlie the Ridge Brook Formation north of Havelock. The contact is interpreted as a disconformity, as bedding in both the Ridge Brook and Gays River formations in the Havelock area is gently dipping to horizontal. The Gays River lies on the Ridge Brook at Havelock yet rests on the basement inlier north of there (Fig. 6), which suggests an overstepping unconformity. The contrast in ages between the Ridge Brook Formation (Tournaisian) and Gays River Formation (Visean) supports the interpretation of a time break.

Lateral Facies Relationships: It is presently not possible to establish a lateral relationship between the Ridge Brook Formation in the Cocagne Subbasin and the adjacent formations of the Sussex Group in the Indian Mountain Deformed Zone. A late Tournaisian age for all Sussex units in the area implies a degree of temporal equivalency. The Ridge Brook detritus was derived from the New Brunswick Platform and transported south. In contrast, the Stilesville, Gautreau, Weldon, and Briggs Cross detritus was almost assuredly derived from a deformed granitoid complex such as that exposed at The Gorge and was transported mainly southwest. Until the tectonic history of the IMDZ is better understood — specifically the sense and amount of movement on the North River Fault (see Park and St. Peter 2009) — the spatial relationship of the Ridge Brook Formation to its southern Sussex Group 'neighbours' will remain unresolved.

Depositional Environment: The dominance of poorly sorted polymictic conglomerates and lithic sandstones, most of which are bedded and show traction structures, suggests deposition mainly by braided streams (Miall 1978, 1981, 1992). The formation is interpreted as an alluvial fan, and the cobble to rare boulder beds in the Catamount area probably represent deposition in a mid-fan setting.

Age: Oxidization and the resulting pervasive red coloration of the Ridge Brook Formation has severely limited the preservation of spores. One assemblage was recovered from an interval of grey shale in a well, Monteagle L-18, drilled by Columbia Natural Resources about 5 km southwest of Pacific Junction just west of the report area (St. Peter 2006a). Although sparse, the assemblage contains *Crassispora trychera* and supports an age no older than latest middle Tournaisian Zone 3B (Fig. 15; Dolby 2001b).

Relationship to Previous Stratigraphy: The strata assigned herein to the Ridge Brook Formation were placed either regionally or locally in the Moncton Group (Stewart 1941a–1941d; Alcock and MacKenzie 1946; Gussow 1953; Hamilton 1961b), the Hillsborough

Formation of the Moncton Group (Gussow 1953; Hamilton 1962), or a coarse facies of the Moncton Formation (St. Peter 1989b). The Ridge Brook Formation is most probably assignable to the Sussex Group. It is older than the unconformably overlying rocks of the Windsor Group, including the Hillsborough Formation.

WINDSOR GROUP

The Windsor Group in the report area (Fig. 8) comprises, in ascending order, the 1) Hillsborough, 2) Gays River and Macumber, 3) Upperton (or equivalent basal anhydrite in the Cumberland Subbasin), 4) Pugwash Mine, and 5) Lime-kiln Brook formations. The Gays River and Macumber formations are largely laterally equivalent. All Windsor formations are Early Carboniferous (Visean). In the report area the group lies unconformably on older Carboniferous rocks or crystalline basement. It is conformably overlain by the Mabou Group in the Cumberland and Sackville subbasins but is unconformably succeeded by the Mabou and Cumberland groups in the eastern Moncton Subbasin (Fig. 6).

The basal Hillsborough Formation comprises mostly coarse terrestrial redbeds. The overlying Gays River Formation is a shallow-water marine algal boundstone, whereas the laterally coeval Macumber Formation is an offshore-marine laminated limestone. The Pugwash Mine Formation is composed predominantly of rock salt. In the Cumberland Subbasin the exhumed Lime-kiln Brook Formation comprises marine shell-bearing carbonates, marine sulphates, and fine- to coarse-grained terrestrial clastics. Rocks that lie above the Pugwash Mine Formation and are correlated with the Lime-kiln Brook Formation in the subsurface of the Sackville Subbasin lack limestone intervals but contain thick units of marine anhydrite and abundant fine-grained grey and red marine to terrestrial siliciclastics.

The Windsor Group was defined by Dawson (1873) and later redefined by Bell (1944) for the Early Carboniferous (Visean) marine and minor associated continental redbeds in the Windsor area of Nova Scotia (Moore 1985). The best reference section of the Windsor Group in that area lies on east bank of Avon River between Avondale and the mouth of Kennetcook River. Bell (1929) divided the Windsor Group of Nova Scotia into five biostratigraphic subzones (A to E) on the basis of macrofossil content (Fig. 15). Giles (1981) subdivided the Windsor Group of Nova Scotia into five major lithostratigraphic cycles that he attributed to transgressive and regressive cycles of the "Windsor Sea." He noted a correspondence between his lithostratigraphic cycles and established biostratigraphic zonations and ascribed a time correlation of the cycles in Nova Scotia with the Visean stages of Britain and Belgium (Giles 1981, his Fig. 4). Giles numbered the cycles from the base of the lowest marine limestone (Cycle 1) to the top of the highest marine carbonate (Cycle 5), matching the cycle boundaries closely with Bell's (1929) macrofaunal Subzones A to E. More recently, von Bitter et al. (2007, their Fig. 2) modified Giles's Cycles 4–5 boundary and placed most of Cycle 5 above Bell's Subzone 5, relegating Cycle 5 nearly entirely to the lowermost Namurian (Pendleian).

In New Brunswick the name 'Windsor' was first applied to Early Carboniferous, largely marine beds by Dawson (1873). The Windsor rocks of southeastern New Brunswick in the current report area were regionally mapped by Flaherty and Norman (1941), Norman (1941a), and Stewart (1941a–1941c). Gussow (1953) subdivided the Windsor beds of southeastern New Brunswick into the subzones defined by Bell (1929) and in the process showed that 1) most of the Windsor in New Brunswick is assignable to Bell's Subzones A and B, and 2) late Windsor marine rocks do not occur in the province. McLeod and Ruitenberg (1978) and McLeod (1980) mapped the Windsor formations in the Dorchester and Hillsborough areas.

In the early 1970s a joint project was initiated between the New Brunswick Department of Natural Resources and the Canadian Department of Regional Economic Expansion to assess the salt potential in southern New Brunswick. Four deep coreholes were drilled in the Windsor evaporites in the western Moncton Subbasin, leading to the discovery of three potash deposits. The deposits were subsequently investigated by private companies who acquired the leases, and the ensuing development work led to the opening of two mines. As part of his M.Sc. thesis, McCutcheon (1981) studied cores from the potash holes, examined cores from numerous shallower holes drilled for industrial mineral and base-metal prospects, and mapped many key sections and outcrops of Windsor marine beds. From this he developed a stratigraphic and paleogeographic model for the marine part of the Windsor Group of southeastern New Brunswick.

No significant geological studies of the Windsor Group in New Brunswick have been conducted since McCutcheon's thesis. For example, the current report focuses on the Carboniferous terrestrial strata below and above the Windsor, examining the Windsor formations in only a cursory fashion. Observations made herein on the Windsor Group are confined mainly to assessing its contacts with bounding units. A notable exception is the discussion here of extending the Windsor stratigraphy from the Cumberland Subbasin of Nova Scotia (see Ryan and Boehner 1994) into the western Cumberland Subbasin and Sackville Subbasin of New Brunswick (Fig. 9). One outcome of this extrapolation is that the names 'Pugwash Mine Formation' and 'Lime-kiln Brook Formation' from Nova Scotian lithostratigraphy are assigned herein to previously unnamed units in New Brunswick (Fig. 9; McCutcheon 1981). (For more detail on this extrapolation, see ***Discussion*** at end of this chapter.

The Windsor Group in the report area has fairly limited surface distribution. It appears along the northern and eastern edge of the Caledonia Uplift from Prosser Brook in the west to Hillsborough and Albert Mines in the east (Plate 4). It is exposed south of the Harvey–Hopewell Fault at Upper Dorchester, Lower Cape, Chemical Road, Hopewell Hill, and Riverside–Albert (Plates 4, 6). Gypsum of the Windsor Group is visible on the Maringouin Peninsula at Grande Anse and Pecks Cove (Fig, 3; Plates 4–6). A small fault-controlled wedge of Windsor limestone crops out at Lockhart Lake (Fig, 3; Plate 6). As well, thick Windsor evaporites occur in the subsurface of the Sackville and Cumberland Subbasins (Fig. 6, 9; Martel 1987; Ryan and Boehner 1994).

Hillsborough Formation

Authors: Wright (1922), revised by Norman (1932) and Norman (1941a).

Type Section: Wright (1922) considered the beds near Hillsborough as typical of the formation. Norman (1932, 1941a) and Gussow (1953) referred in general to exposures west of the headwaters of Weldon Creek and those overlying basement along Wilson Brook south of Albert Mines as being representative of the unit. McCutcheon (*in* Williams et al. 1985) recommended the beds on West Branch Turtle Creek just west of Albert Mines as the type section.

In keeping with McCutcheon, the type section of the Hillsborough Formation is designated herein as the beds along West Branch Turtle Creek and Stuart Brook (a west tributary of West Branch Turtle Creek) from the unconformable contact with the underlying Albert Formation to the base of the Gays River Formation near Berryton, Albert County (NTS 21 H/15; Plate 4).

Reference Section: A good reference outcrop occurs along the tidally washed section at Edgetts Landing (NTS 21 H/15; Plate 4) on Petitcodiac River.

Definition and Description: The Hillsborough Formation is the basal unit of the Visean Windsor Group in the report area. It is a coarse-grained terrestrial redbed sequence lying unconformably on the Sussex Group and older rocks and is concordantly succeeded by the marine Gays River and Macumber formations.

The Hillsborough Formation comprises polymictic conglomerate, lesser lithic sandstone, and minor red mudstone. The polymictic conglomerate beds are mostly reddish brown (Fig. 28) to locally grey or greyish green. The grey beds tend to occur near the base of the formation where it overlies basement or the Albert Formation. Conglomerate typically appears as sequences of stacked interbeds in which individual beds are dominated by granules, pebbles, or cobbles. Massive beds up to 3 m thick are present in an outcrop on an old woods road along the east side of Frederick Brook just north of the Edgetts Landing Fault (Plate 4). Boulders up to 30 cm in diameter occur in Hillsborough beds overlying the Albert Formation at Stuart Brook; even larger boulders (up to 60 cm in diameter: see Norman 1932) appear in Hillsborough beds on the north side of the Caledonia Uplift. The conglomerate generally occurs in horizontal layers or medium-scale cross-beds. Cut-and-fill structures with channels filled by lenticular beds of conglomerate are visible in the section along Petitcodiac River at Edgetts Landing. Clasts include schistose felsic and mafic volcanic rocks, metasedimentary rocks, chert, granite, porphyritic granite, and gabbro. Rounded limestone clasts are present in the formation near the headwaters of Gray Brook (McLeod 1980). The clasts vary from subangular to well rounded and invariably are poorly sorted. Most beds have a slightly muddy lithic sandstone matrix.

Coarse-grained to granular and pebbly lithic sandstone occurs as parallel-stacked or lenticular beds within conglomerate intervals. Parallel beds of lithic sandstone within conglomerate are present in exposures along Cat Creek. The lenticular beds of sandstone at Edgetts Landing resulted from erosion of horizontal beds and subsequent channel-filling by cross-beds of conglomerate and sandstone. Lithic grains in the sandstones compositionally resemble the larger clasts in the interbedded conglomerates. Both the Hillsborough conglomerates and lithic sandstones display varied degrees of induration. In places, the beds are so friable as to crumble in the hand. Elsewhere, the conglomerates form resistant knobs and cliffs, such as in the hills between Prosser Brook and Rosevale.

The Hillsborough Formation locally contains beds of sandy mudstone and mudstone. Such beds occur at Edgetts Landing, where they are up to 60 cm thick, discontinuous, and cut out by overlying channels filled with conglomerate. Nodules of limestone appear in the finer grained redbeds (McLeod 1980).

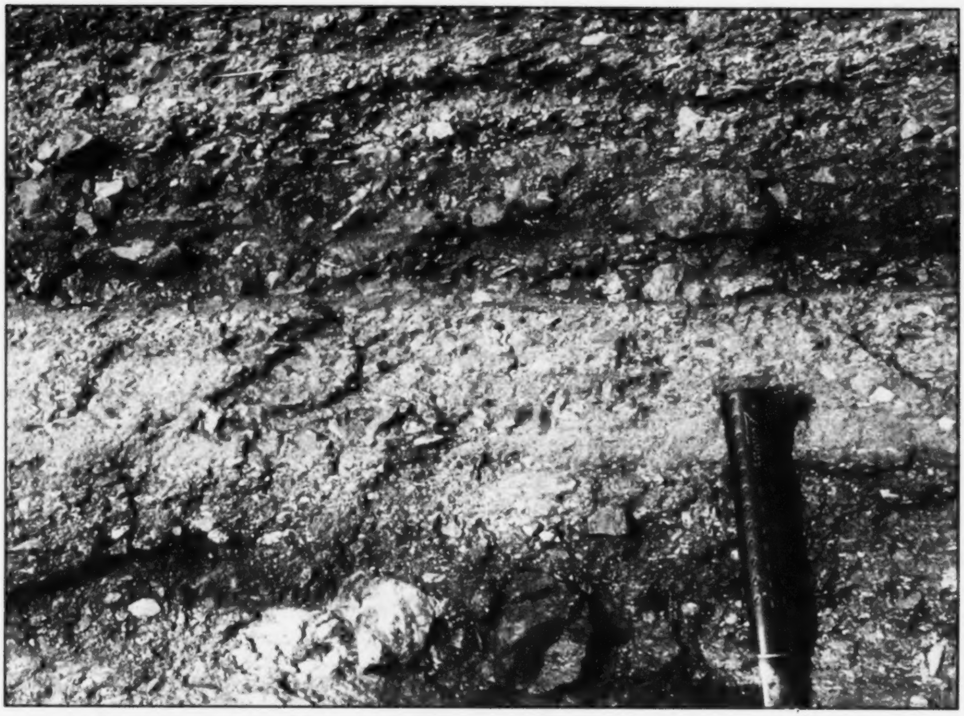


Figure 28. Red, angular, polymictic, pebble to cobble conglomerate of the Hillsborough Formation at Prosser Brook.

Distribution and Thickness: The Hillsborough Formation occurs at surface only within the Hillsborough map area (Plate 4) in the Moncton Subbasin (west side of Petitcodiac River) and on the margins of the adjacent Caledonia Uplift (Fig. 6). The formation occurs along the north-northeastern edge of the Caledonia Uplift from Prosser Brook through Steevescote to Weldon, south of Hillsborough in a horseshoe-shaped area from Frederick Brook to Edgetts Landing, and along the headwater tributaries of Peck Creek and Wilson Brook.

A special note is made here with respect to assigning the red conglomerate and grit between Weldon, Steevescote, and Hillsborough to the Hillsborough Formation. Exposures on the high ground east of Steevescote were placed in Zone 1 of the Petitcodiac Series by Wright (1922). Norman (1941a) allocated those beds to the same stratigraphic level but relabelled them 'Hopewell Group.' Gussow (1953), McLeod (1980), and St. Peter (1989b) likewise placed them in the Hopewell Group (Mabou Group of the current usage). No paleontological evidence exists to assist with their possible stratigraphic position. Nonetheless, they are placed herein in the Hillsborough Formation for the following reason. The beds south of Weldon near the mouth of Weldon Creek dip moderately to the southeast. This suggests a synclinal axis south of those outcrops and implies they were rotated (turned up) by the Salem Fault in a fashion similar to what occurred in the footwall syncline in the unconformably underlying Weldon Formation between Steevescote and Salem (Plate 4). Conversely, beds of the Hopewell Cape Formation immediately north of Weldon and adjacent to the Salem Fault dip shallowly as they do on the east side of Petitcodiac River near Pré-d'en-Haut. In other words, the coarse redbeds between Weldon, Steevescote, and Hillsborough are reassigned herein to the Hillsborough Formation in keeping with the interpretation that the Hillsborough Formation predates the Salem Fault, whereas the Hopewell Cape Formation postdates the fault.

Wright (1922, p. 18) estimates a maximum thickness for the Hillsborough Formation of 730 m in the Hillsborough area. In Well 266 at Baltimore, the contact between reddish brown mudstones of the Weldon Formation (Sussex Group) and coarse conglomerates and grits of the overlying Hillsborough Formation occurs at a depth of 757 m. At the top of the well, the Hillsborough beds are capped by about 13 m of sandstones of the Boss Point Formation (Cumberland Group). Assuming a regional dip of 15°NW, the Hillsborough Formation there is about 715 m thick. The Hillsborough thins over a fairly short distance northward away from the Caledonia Uplift and onto the south flank of the Westmorland Uplift. For example, the formation is about 160 m thick in Well 334 near the community of Little River but is absent in Well 146, which is located farther north just west of Colpitts Settlement and Plate 4. This relationship suggests the formation thins out to the south of Well 146.

Lower and Upper Boundaries: The lower boundary of the Hillsborough Formation ranges from an angular unconformity to a disconformity. It is not exposed in outcrop in the mapped area; narrow concealed intervals hide the contact along several small tributaries of Prosser Brook, Stuart Brook, West Turtle Creek, and Bray Brook, all of which drain northward off the Caledonia Uplift. A significant angular divergence in bedding between the Albert Formation and Hillsborough Formation appears in all these stream sections between Prosser Brook and Rosevale. The absence of the entire Sussex Group at that contact confirms an erosional break in the succession. An unconformity at the base of the Windsor Group is easily discerned on seismic reflection profiles in the eastern Moncton Subbasin (Fig. 13, 14; St. Peter 1992, 1993). Hillsborough strata overstep the Horton and Sussex groups and lie nonconformably on basement rocks near the headwaters of Wilson Brook and Peck Creek.

The upper boundary of the Hillsborough Formation is concordant with the Macumber Formation. It is exposed on the south side of a woods road leading east from an old gypsum quarry, about 500 m west of Well 703 at Edgetts Landing (see McCutcheon 1981, his Map 12, outcrop MA112A). There, the basal 35 cm of limestone of the Macumber Formation has siliciclastic sand and pebbles resembling those in the underlying Hillsborough. The concordant contact between the Hillsborough and Macumber formations is also exposed at the head of Gray Brook 3.5 km southwest of Hillsborough (McLeod 1980, p. 10).

Both the upper and lower contacts of the Hillsborough Formation appear in the subsurface at Baltimore in Well 266. There, the unconformable contact between mudstones of the underlying Weldon Formation and coarse conglomerates and grits of the Hillsborough Formation occurs at a depth of 757 m. At the top of the well, the Hillsborough beds are capped by sandstones of the unconformably overlying Boss Point Formation.

Lateral Facies Relationships: Norman (1932) observes that the Hillsborough Formation on the north side of the Caledonia Uplift changes from massive coarse conglomerates along the uplift to a finer facies of coarse grits with pebble conglomerate interbeds to the north away from the uplift. Boulders up to 30 cm in diameter are common in the formation at Stuart Brook and Prosser Brook, but the largest clasts are only up to 5 cm in diameter in conglomerates below the Macumber Formation on Cat Creek.

Depositional Environment: Shroder (1963, p. 76) wrote "... the Hillsborough Formation seems to have been deposited under fluviatile conditions in a rapidly subsiding basin." The formation is a wedge-shaped deposit that thins to the north away from the Caledonia Uplift. The apparent decrease in clast size in conglomerate beds away from the uplift also suggests a southern provenance. The clast composition dominated by volcanic, plutonic, and metasedimentary detritus, the clast-size distribution, and the deposit shape all suggest an alluvial fan complex sourced from the south and thinning toward the north.

Conglomerates of the Hillsborough Formation are predominantly clast-supported, and most have a sandy or gritty sand matrix. Conglomerates and interbedded sandstones typically display parallel beds or cross-beds, indicating they are waterlaid deposits. Cut-and-fill structures occur in better exposures such as on Petitcodiac River at Edgetts Landing. The Hillsborough Formation is thus interpreted as an alluvial fan complex in which most beds were deposited by high-energy braided streams draining to the north off the Caledonia Uplift.

Age: No potentially spore-bearing grey beds have been mapped in the Hillsborough Formation. Early Visean is considered a likely age on the basis of dates for the unconformably underlying Sussex Group, the youngest of which are latest Tournaisian (see ***Gautreau Formation*** and ***Weldon Formation,*** earlier). The concordantly overlying Gays River and Macumber formations in Atlantic Canada (Fig. 9) are assignable to the NS concurrent range zone and are probably middle Visean (V2; Fig. 15), according to both palynological and faunal evidence (Utting 1987).

Relationship to Previous Stratigraphy: Wright (1922) proposed the name 'Hillsborough Series' to describe a concordant sequence of coarse redbeds, limestone, fine redbeds, and anhydrite (gypsum) in the Hillsborough area. He divided the series into four zones and labelled the basal coarse redbeds as 'Zone 1.' Norman (1932) used the name 'Hillsborough formation' for all four of Wright's zones. However, he later (Norman 1941a) formalized the nomenclature and restricted his Hillsborough Formation to the basal redbeds (Zone 1) of Wright's Hillsborough Series. At the same time, Norman (1941a) combined his Hillsborough Formation with the underlying Weldon Formation into a new group called the 'Moncton Group.' In other words, Norman removed the Hillsborough Formation from the Hillsborough Series, even though he recognized an angular unconformity between the Weldon and Hillsborough formations. Norman (1941a) dropped the name 'Hillsborough Series' and used the name 'Windsor Series' for the limestone, redbeds, and anhydrite (gypsum) above the Hillsborough Formation.

Gussow (1953) retained Norman's use of the Hillsborough Formation as the upper unit in the Moncton Group. Gussow (1953) and Shroder (1963) suggested that the unconformity at the base of the Hillsborough Formation may exist throughout the subbasin but noted that the close similarity in rock types between the Weldon and Hillsborough formations precluded a definitive conclusion. Gussow (1953) accordingly included the Weldon Formation in the Horton Group (Sussex Group as now defined) but assigned the Hillsborough Formation to the superjacent Windsor Group with which it is conformable.

Seismic reflection profiles show a basin-wide angular unconformity between the deformed (faulted and folded) Horton and Sussex groups (including the Weldon Formation) and the overlying less deformed Hillsborough Formation (St. Peter 1992, 1993). St. Peter (1992) therefore followed Gussow (1953) in placing the Hillsborough Formation in the Windsor

Group. This conforms to Wright's (1922) original contention that the basal redbeds (i.e., the Hillsborough Formation) form a natural depositional sequence with the overlying limestone, redbeds, and sulphates. At the same time, St. Peter (1992) suggested abandoning the term 'Moncton Group.' Consequently, the lower contact of the coarse redbeds that characterize the Hillsborough Formation is used to define the boundary between the Sussex Group and Windsor Group (Fig. 9).

Norman (1941a), Gussow (1953), Shroder (1963), and McLeod (1980) placed the coarse redbeds along the lower part of Weldon Creek and similar rocks on the east side of Petitcodiac River along lower Boyd Creek in the Hillsborough Formation. These beds are assigned herein to the Hopewell Cape Formation of the Mabou Group. The rationale for doing so is presented earlier under ***Weldon Formation***.

Gays River Formation

Authors: Boehner (1977), Giles et al. (1979), McCutcheon (1981).

Type Section: The type section occurs at Imperial Oil Ltd. diamond-drill hole GR256 in depth interval 15.5 m to 48.2 m. The hole is located near the Gays River mine in Halifax County, Nova Scotia (NTS 11 E/03; Ryan 1978a, 1978b).

Reference Sections: The best reference section in the report area lies along the headwaters of a small tributary of Wilson Brook about 3.5 km southwest of Albert Mines (NTS 21 H/15; see McCutcheon 1981, his Map 12, outcrop MA107), where the Gays River section lies on crystalline basement (Fig. 29). A second reference section occurs outside the report area in diamond-drillhole P-10 near Peekaboo Corner (Fig. 6).

Definition and Description: The Gays River Formation in New Brunswick is described by McCutcheon (1981) as dominantly grey to yellowish brown marine algal boundstone. The formation is less than 80 m thick and typically lies unconformably on crystalline basement or concordantly on the Hillsborough Formation. The upper contact is either transitional with sulphates of the Upperton Formation or unconformable with post-Windsor units.

The boundstone occurs in lenses and thick to very thick non-parallel beds or unbedded mounds. The mounds vary in length from less than 1 m to several metres and have length-to-height ratios of 3 or more. Planar, low domal to columnar stromatolites are present locally in the boundstone. Near Peekaboo Corner (Fig. 6) the boundstone has a clotted texture, due to blocky calcite-filled pores, and is mottled. The mottling results from dark-hued algal masses of yellowish brown calcite that are surrounded by light-hued interstitial wackestone sediment. The algal masses contain minor encrusting bryozoans and foraminifera.

In places, the formation is characterized by a basal bafflestone showing a vertical algal fabric and small smooth-shelled brachiopods (McCutcheon 1981). The bafflestone is typically overlain by a thin interval of thin-bedded wackestone or packstone.

A modest macrofaunal assemblage occurs near the base of the Gays River Formation in New Brunswick. It is described by Bell (1929) and listed by Gussow (1953) and McCutcheon

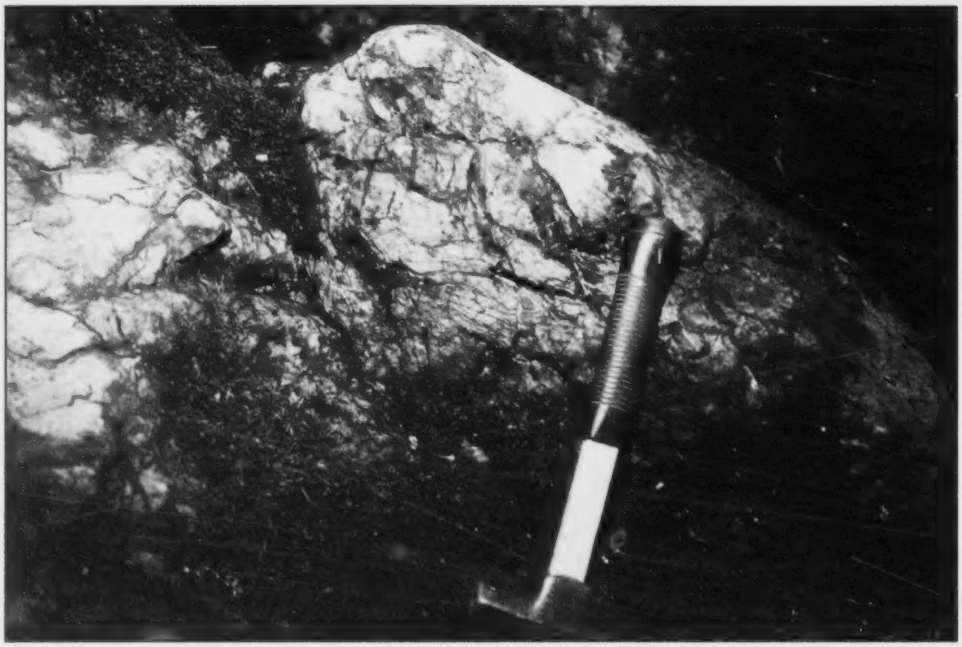


Figure 29. Algal mounds in the Gays River Formation lying just above crystalline basement on the headwaters of a small tributary of Wilson Brook, about 3.5 km southwest of Albert Mines.

(1981). The shells include the smooth-shelled brachiopod *Beecheria* sp. (most common), the brachiopod *Ovatia lyelli*, pelecypods *Leptodesma dawsoni*, *Leptodesma borealis*, *Lithophaga poolii* and *Streblopteria simplex*, the gastropod *Pteronites gayensis* and the serpulid worm *Spirorbis caperatus*. McCutcheon also reports high-spired gastropods encrusting bryozoa and ostracods. Globensky (1970) identifies several species of foraminifera.

Distribution and Thickness: Exposures of the Gays River Formation are present near Berryton on the west side of West Branch Turtle Creek and just south of Albert Mines at the headwaters of Wilson Brook. In Well 146 west of Colpitts Settlement (Plate 4), limestone sits on marble and pelite of the crystalline basement at depth interval 1379 m to 1413 m. The limestone is interpreted from drill cuttings to be Gays River Formation.

McCutcheon (1981) reports a thickness of 2 m to 80 m for the Gays River Formation in the Moncton Subbasin. A minimum thickness for the section at Wilson Brook is 8 m; the upper part of the formation is concealed. The section is 19 m thick in Well 328 that lies 0.5 km north of Berryton, and it is 34 m in Well 146 located to the northwest.

Boundaries and Lateral Facies Relationships: The lower boundary of the Gays River Formation is exposed along Wilson Brook southwest of Albert Mines where algal boundstone overlies pre-Late Devonian granitoid rocks (McCutcheon 1981, p. 29). However, about 250 m north of the basement contact, Gays River facies overlie and interfinger with laminated carbonates typical of the Macumber Formation (McCutcheon 1981, his Fig. 3-8).

The upper boundary of the Gays River Formation is not exposed in the report area. McCutcheon (1981) notes gypsum porphyroblasts in the upper 9 m of the Gays River limestone at Peekaboo Corner (Fig. 6) on the northeastern margin of the Kingston Uplift, interpreting this to suggest that the Gays River and Upperton formations may be in part laterally equivalent or at least transitional.

In places, the Gays River Formation is unconformably overlain by strata younger than the Windsor Group. For example, between Wilson Brook and McHenry Brook, the east-southeast-striking Gays River Formation is succeeded by the north-striking Hopewell Cape Formation (Plate 4). The divergence in strike between the two formations and their considerable difference in age demands an unconformity. Another demonstration of the unconformity appears on the west side of West Branch Turtle Creek near Berryton and in adjacent Well 328, where Gays River carbonate is overlain by the Boss Point Formation. The middle Visean age of the Gays River Formation (see ***Age***, below), combined with the late Namurian–early Westphalian A age of the Boss Point Formation (see ***Boss River Formation***, later), necessitates an unconformity in this area.

Depositional Environment: The Gays River Formation represents a series of basement-fringing or perhaps barrier algal buildups deposited in a shallow sublittoral or low intertidal environment. McCutcheon (1981) bases this interpretation on models by Heckel (1974) and Ahr (1971), which show that the vertical and lateral distribution of carbonate facies (non-laminated mounds, bafflestone, wackestone, packstone, stromatolite morphology, and faunal content) are analogous to modern-day buildups in Shark Bay, Western Australia (Hagan and Logan 1974).

Age: As noted earlier, Bell (1929) subdivided the Windsor Group into five subzones using brachiopods, corals, mollusks, and trilobites (Utting 1987). He considered Subzones A and B as part of the early Windsor, which he designated Zone *Composita dawsoni*, and Subzones C, D, and E to be late Windsor or Zone *Martinia galataea*. He correlated the early Windsor with the middle Visean of the Avonian of northern Europe. He also provided (1929, p. 66–68) a comprehensive table of Windsor fauna in Nova Scotia and offered detailed descriptions and figures for most species.

McCutcheon (1981, p. 72) gives a table of fossils for the Gays River and Parleeville formations in New Brunswick. Utting (1987) summarizes the history of faunal, floral, microfaunal, and palynological studies for the Windsor Group (also see Bell 1929, 1960; Lewis 1935; Globensky 1967; Mamet 1970; Hacquebard 1972; Utting 1978; von Bitter and Austin 1984). On the basis of various biostratigraphic zonations and cross correlations, Utting (1987, his Tables 2 and 3) concludes that the basal Windsor marine rocks (Bell's Subzone A or the Gays River and Macumber formations) are middle Visean, equivalent in age to the Arundian substage of the British Isles.

Relationship to Previous Stratigraphy: The name 'Gays River Formation' was introduced by Boehner (1977) for basal Windsor carbonates in the Musquodoboit Subbasin of Nova Scotia. The formation was further described by Giles et al. (1979). The name was later applied to stratigraphically and lithologically similar rocks in New Brunswick by McCutcheon (1981). No changes have been made herein to the regional definition of the stratigraphy of the Gays River Formation in New Brunswick as set out by McCutcheon (1981).

Macumber Formation

Authors: Weeks (1948); McCutcheon (1981) for New Brunswick.

Type Section: Weeks (1948 p. 74–75) introduced the name 'Macumber Formation' for the distinctive thin-bedded carbonates on the south side of Minas Basin in the Londonderry and Bass River map areas of Nova Scotia. He named the formation from a quarry section on the Leander Macumber farm near Cheverie, 10 km north of the mouth of Avon River, presumably considering the section as typical of the formation. Moore (*in* Williams et al. 1985) proposes beds on the east side of Avon River southwest of Cheverie (Hants County) as the type section for the Macumber Formation (NTS 21 H/01).

Reference Sections: McCutcheon (*in* Williams et al. 1985) designates two reference sections in New Brunswick in the southwestern Moncton Subbasin: 1) on a small tributary of Hammond River (NTS 21 H/05) about 30 km south-southwest of Sussex, and 2) in diamond-drillhole P-11 near Peekaboo Corner (NTS 21 H/12; Fig. 6). The sections are located outside the report area and are described in detail by McCutcheon (1981).

Definition and Description: The Macumber Formation is characterized by thin parallel-laminated to thin parallel-bedded marine limestone. The formation is less than 20 m thick in New Brunswick. It lies concordantly above the Hillsborough Formation (Fig. 30) and is either conformably and gradationally overlain by sulphates of the Upperton Formation or unconformably overstepped by rocks of the Mabou Group and younger Carboniferous formations.

The laminae and thin beds of limestone comprise alternating dark (brownish black to black) wackestone and light (pale olive grey to olive grey) siliciclastic wackestone and intraclastic or pelletoidal packstone (McCutcheon 1981). Some exposures in the Edgetts Landing area weather reddish brown or maroon. The packstone contains small amounts of shell debris, foraminifera, and whole and disarticulate ostracods.

The Macumber Formation contains minor planoconvex 'inhomogeneous beds' 0.2 m to 1.5 m thick that McCutcheon (1981) describes as comprising floatstone (intraformational breccia), packstone, and boundstone. The convex sole of the thickest inhomogeneous beds contains minor boundstone displaying clotted or stromatolitic fabric. Most of the inhomogeneous layers are composed predominantly of floatstone with abundant intraclasts plus pellets, ooliths, bioclasts, and siliciclastic fragments. The tops and distal thinner parts of the inhomogeneous beds consist largely of packstone.

Distribution and Thickness: In the report area the Macumber Formation is exposed only in the Hillsborough map area (Plate 4). Outcrops are present near the headwaters of Wilson Brook, along tributaries of Gray Brook, and west of Hillsborough along Cat Creek. The formation varies from 9 m to 18 m thick in the Moncton Subbasin (McCutcheon 1981).

Lower and Upper Boundaries: The lower boundary of the Macumber Formation is concordant with the Hillsborough Formation. It is exposed on the south side of a woods road leading east from an old gypsum quarry about 500 m west of Well 703 at Edgetts Landing

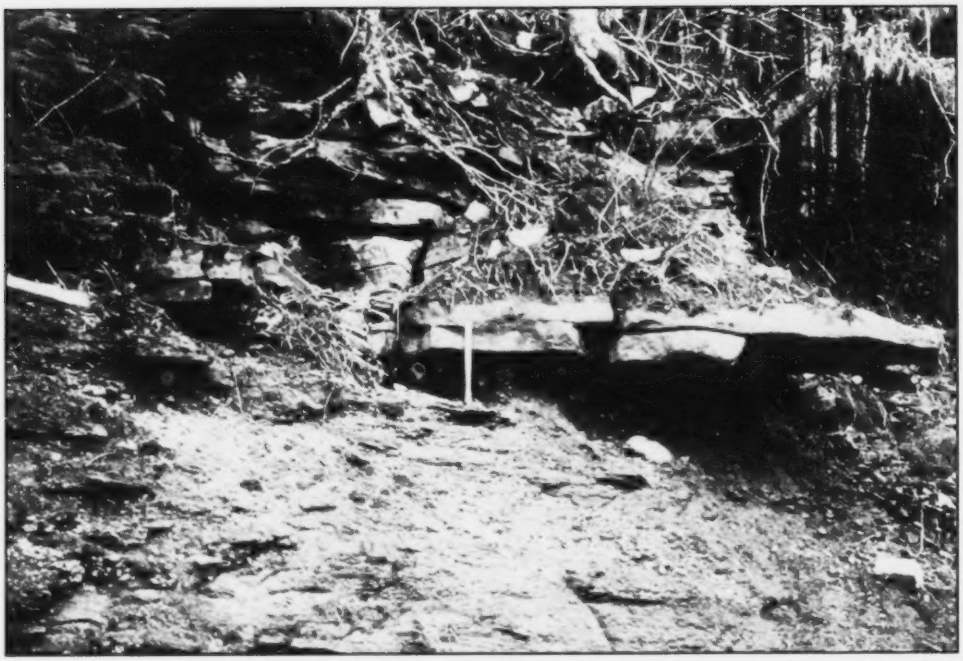


Figure 30. Flaggy grey, parallel-laminated limestone of the Macumber Formation lying in parallel disposition above reddish brown conglomerate of the Hillsborough Formation near Edgetts Landing.

(Fig. 30; see McCutcheon 1981, his Map 12, outcrop MA112A). The basal 35 cm of the Macumber contains significant siliciclastic sand and pebbles set in calcite cement. The pebbles include quartz, rhyolite, and gabbro. Above the siliciclastic-rich basal bed, the formation comprises characteristic thin-laminated wackestone and packstone.

The upper boundary of the Macumber Formation is varied, its nature and chronostratigraphic significance differing according to whether the overlying strata are Windsor Group or Mabou Group. Near Wilson Brook just southwest of Albert Mines, for example, the Macumber Formation is conformably and regressively overlain by a tongue of the Gays River Formation (McCutcheon 1981, his Fig. 3-8). A similar relationship between the Gays River and Macumber formations appears near Peekaboo Corner (Fig. 6) adjacent to crystalline basement of the Kingston Uplift, where algal boundstone of the Gays River Formation overlies parallel-laminated limestone of the Macumber Formation (McCutcheon 1981, his Fig. 3-1a). In the same area but farther north of the basement, the Macumber Formation is conformably overlain by mudstones of the Upperton Formation (Windsor Group) (McCutcheon 1981, his Fig. 3-1a: boreholes P-4, P-5, P-7, P-9, and P-14).

The contact of the Macumber Formation with the overlying Mabou Group is not exposed in the Moncton Subbasin (McCutcheon 1981), but map relationships indicate an unconformity. Along Cat Creek 6 km west of Hillsborough, Macumber limestone on the southwest side of the creek is interpreted to be overlain by coarse redbeds of the Hopewell Cape Formation (Plate 4). However, if the Hopewell beds thin out from the north, the absence of outcrops accords with this interpretation, and the even younger Boss Point Formation could rest on the Macumber. In either case, the absence of upper formations of the Windsor Group points to an unconformity at the top of the Macumber Formation in this area.

Lateral Facies Relationships: As noted above and convincingly argued by McCutcheon (1981), the Macumber Formation is laterally equivalent to the Gays River Formation. Both formations define the basal carbonate unit of the Windsor Group. The Macumber represents a deeper water facies than the Gays River buildups (see ***Gays River Formation***, earlier).

Depositional Environment: The Macumber Formation is interpreted as a sublittoral, below-wave-base lithofacies because 1) throughout its distributed area it occurs basinward of the algal buildups of the Gays River Formation, 2) it contains sufficient organic matter to give the beds a fetid odour when broken, suggesting anoxic conditions in the water column during deposition, and 3) it contains no desiccation structures or ripple-laminated bedforms that inevitably would appear in supratidal or shallow subtidal environments (McCutcheon 1981).

The thin parallel laminae of the Macumber Formation are not algal or cyanobacterial (Schenk 1967), which likely negates the possibility of a supratidal or intertidal origin (Kendall 1992). Instead, they are composed essentially of transported allochthonous carbonate sediment. The presence of disarticulated shell debris also implies that much of the sediment was transported from a shallower water carbonate shelf into deeper water.

Age: The Macumber Formation is sparsely fossiliferous. Ostracods and tubular foraminifera are ubiquitous but not common (McCutcheon 1981). Brachiopods and bryozoan fragments occur sparsely in floatstone beds. Seemingly as a result of this faunal scarcity, the age of the Macumber Formation is in dispute. Bell (1929) originally interpreted the Macumber as basal Windsor Group and accordingly assigned it an age equivalent to the Subzone A Gays River Formation. Mamet (1970) suggests a middle late Visean age on the basis of sparse microfauna. Moore (*in* McCutcheon and Moore 1985) assigns the depauperate megafauna to Bell's (1929) Subzone B or late middle Visean (Fig. 15).

Given that little doubt exists concerning the lateral equivalency of the Gays River and Macumber formations, it is suggested herein that their age is essentially synchronous. Utting (1987, his Tables 2 and 3) concluded after an exhaustive literature review that the basal marine rocks of the Windsor Group (Bell's Subzone A or the Gays River and Macumber formations) are middle Visean, equivalent to the Arundian substage of the British Isles.

A spore-bearing sample from an outcrop of Macumber limestone in the Edgetts Landing area (spore locality 82 on Plate 4) yielded an age of early middle Visean, probably lower NS Zone (Dolby 2005; Fig. 15).

Relationship to Previous Stratigraphy: Weeks (1948, p. 74–75) introduced the name 'Macumber Formation' for the thin-bedded carbonates on the south side of Minas Basin, Nova Scotia (see ***Type Section***, above). The stratigraphy of the Macumber Formation as used herein has not been modified from that originally defined by McCutcheon (1981) for the Moncton Subbasin. It is equivalent to Zones 3 and 4 of the Hillsborough Series of Wright (1922), map unit 8 of the Windsor Series of Norman (1941a), limestone map unit **MWL** of the Windsor Group of Gussow (1953), and limestone map unit 7a of the Windsor Group of McLeod (1980).

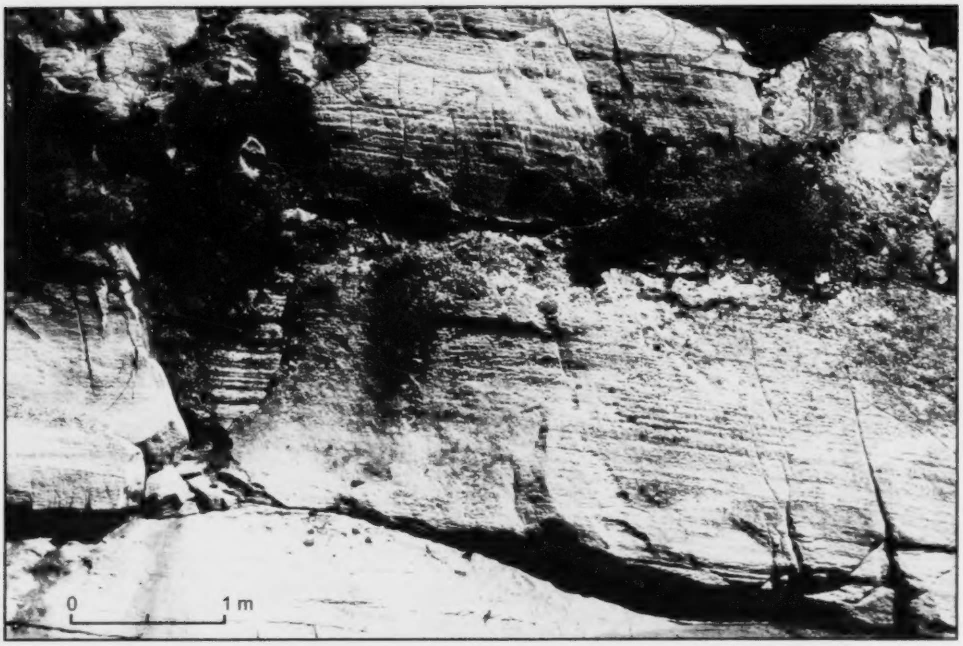


Figure 31. Thin-bedded gypsum and anhydrite of the Upperton Formation in a cliff face along the south bank of Wilson Brook, Wilson Brook Protected Natural Area.

Upperton Formation

Authors: Anderle et al. (1979), revised by McCutcheon (1981).

Type Section: Anderle et al. (1979) do not define a type section for the Upperton anhydrite but imply by the name that the gypsum exposures around Upperton, Kings County (NTS 21 H/12; Fig. 6), near Sussex are representative of the unit.

Reference Sections: McCutcheon (1981, p. 173) designates two reference sections from boreholes: 1) diamond-drill hole P-11 in the Peekaboo Corner area about 500 m north of crystalline basement of the Kingston Uplift (NTS 21 H/12; Fig. 6), and 2) Well 43 just northeast of Sussex at the present location of the McCully Field (NTS 21 H/11; Fig. 6). Both sections are situated outside the report area; see Appendix 1 for more details. Excellent surface sections of the Upperton Formation are exposed in the report area within the Wilson Brook Protected Natural Area about 3 km southwest of Albert Mines (Fig. 31).

Definition and Description: The Upperton Formation in the report area is a unit of marine anhydrite that is typically largely gypsified in outcrop (McCutcheon 1981). Subterranean caverns, formed in the sulphates from a post-Windsor Carboniferous karstification event, are filled by limestone-clast conglomerate, maroon siltstone, shale, and minor sandstone. The Upperton conformably overlies the Gays River and Macumber formations and is interpreted to concordantly underlie the rock salt correlated with the Pugwash Mine Formation in the Sackville Subbasin.

Gypsum and anhydrite of the Upperton Formation in the Hillsborough area are described by Wright (1922), Norman (1941a), Gussow (1953), Sund (1958), Hamilton and Barnett (1970), McLeod (1980), and McCutcheon (1981). The reader is referred in particular to Sund (1958) and McCutcheon (1981) for greater detail than is reported here.

McCutcheon (1981) describes the Upperton Formation as essentially comprising two parts: host rocks and authigenic sulphates. Where the host rocks are still preserved such as in reference borehole sections (cited above) in the southwestern Moncton Subbasin (McCutcheon 1981), they comprise fine-grained grey calcareous sandstone, greenish grey calcareous shale or mudstone, and grey laminated wackestone and packstone. The laminated wackestone–packstone is indistinguishable from the underlying Macumber limestone. In a gypsum quarry 1 km west of Edgetts Landing, just south of Gray Brook, minor beds of grey, thin-bedded, parallel-laminated shale and lesser sandy limestone host rock appear within the replacive gypsum (McLeod 1980, his Fig. 7). In the same area, reddish brown or maroon siltstone and sandstone "impurities" occur in the gypsum (McLeod 1980, p. 14).

The host rocks are to varied degrees replaced or displaced by authigenic gypsum or anhydrite, which show complex textural and interpreted paragenetic relationships (McCutcheon 1981). Anhydrite, presumably after primary gypsum, occurs as nodules and coalescing nodules in the host rock. It also appears in massive intervals or as mosaic anhydrite in which the primary host rock is preserved as irregular clots or selvages (McCutcheon 1981, p. 60). Interstratified anhydrite and gypsum crop out along Wilson Brook (Fig. 31; Hamilton and Barnett 1970). Secondary or late gypsum occurs as microscopic crystals within anhydrite nodules, as satinspar veins, and as large black selenite poikioblasts in crystals up to 1 cm long. Selenite poikioblasts, where present, do not cut bedding surfaces, suggesting a possible early diagenetic origin. Hamilton and Barnett (1970) report selenite porphyroblasts in anhydrite.

Near surface, the anhydrite is largely replaced by alabasterine gypsum. Features and apparent controls on the gypsification process are discussed in Wright (1922), Sund (1958), and Hamilton and Barnett (1970). The last-named authors note that the gypsum forms a cap or crust on the anhydrite up to 30 m thick and that the cap is unrelated to original stratification. Zones containing anhydrite nodules are common in many areas, particularly where the gypsum layers have a limited thickness (Hamilton and Barnett 1970). The nodules range from 6 in to 3 ft (15–90 cm) in diameter and are tightly packed in a matrix of gypsum. The nodule-containing zones vary from a few feet to more than 20 ft (8 m) in thickness and apparently represent zones of active hydration. The location and orientation of the quarries indicate that the gypsum shows a strong association with minor faults, suggesting that gypsification was enhanced by means of water circulation along fractures. Sund (1958) notes an association of gypsification with fractures.

Wright (1922), Norman (1941a), Gussow (1953), and Sund (1958) all described a thin unit of redbeds at the base of the gypsum or anhydrite of the Upperton Formation in the Gray Brook and Wilson Brook areas. Wright (1922) noted red sandstone and shale, Norman (1941a) reported red shale and gritty conglomerate, Gussow (1953) described only red shale with limestone nodules, and Sund (1958) noted only fine-grained marl and shale. The first three authors mapped the unit as a laterally continuous stratigraphic interval at Gray and Wilson brooks. Sund mapped the redbeds as a discontinuous unit, showing them as thin lens in three places (Sund 1958, his Map 2). All subsequent reports (Hamilton 1965; Hamilton and Barnett

1970; McLeod 1980; McCutcheon 1981) either failed to recognize or failed to separate the redbed unit. Yet the unit definitely exists, at least in part, as thin lenses, as evidenced by diamond-drill hole data from the Gray Brook area (Sund 1958). The lenses may represent subterranean cavern-fill deposits along the Macumber–Upperton contact (see ***Depositional Environment***, below).

Limestone-clast breccia (conglomerate), maroon siltstone, shale, and minor sandstone of the Upperton Formation are present in the subsurface near Curryville. The conglomerate and finer clastics occur as irregular masses or lenses at random stratigraphic levels in the gypsum and, in some holes, replace nearly the full 80 m of the formation (McLeod 1980, his Fig. 7). The conglomerate lenses and interbedded siltstone–shale–sandstone lenses are highly varied and range up to 30 m thick in the two holes illustrated by McLeod (1980). In describing the clastics, McLeod (1980, p. 14) notes "the most common lithology is a sedimentary breccia [conglomerate] containing varying proportions of limestone clasts up to 8 cm in diameter in a calcareous maroon mudstone matrix. Other clasts include maroon sandstone, siltstone and basement rocks. Minor amounts [beds] of maroon sandstone and siltstone containing green reduction spheres also occur." He also notes that maroon shale is associated with the siltstone and sandstone intervals in the conglomerate.

Distribution and Thickness: In the report area the Upperton Formation is exposed only in the Hillsborough map area (Plate 4). The formation crops out along Wilson Brook and Gray Brook and in several disused quarries adjacent to those brooks.

Neither McCutcheon (1981) nor McCutcheon and Moore (1985) give a thickness estimate for the Upperton Formation in the Hillsborough area. Hamilton and Barnett (1970) indicate a thickness of at least 38 m from drillhole intersections in the Gray Brook area. McLeod (1980) suggests a thickness of 40 m for the gypsum and anhydrite interval in the Gray Brook area. Drillholes near Demoiselle Creek in the Curryville area (Plate 4) indicate that the Upperton sulphates were at least 80 m thick before dissolution and entombment of cavern-fill redbed deposits.

Lower and Upper Boundaries: The lower boundary of the Upperton Formation is interpreted to be conformable with the underlying Macumber Formation (McCutcheon 1981). The interpretation is supported by the fact that laminated wackestone and packstone beds in the Upperton are indistinguishable from those in the Macumber. At the reference section in Plumweseep No. 1, McCutcheon (1981) draws the lower contact where nodular sulphate first becomes 'obvious' in ascending the section. In the Gray Brook area southwest of Hillsborough, sulphates and/or fine-grained redbeds of the Upperton Formation rest on laminated limestones of the Macumber Formation. In the Wilson Brook area, the Upperton sulphates contain caverns filled with limestone-clast conglomerate and minor fine-grained redbeds. Locally the conglomerates and redbeds separate the Upperton Formation from the underlying Gays River and Macumber formations.

The upper boundary of the Upperton Formation varies from conformable to unconformable. In the axial part of the Moncton Subbasin at Plumweseep No. 1, the Upperton sulphates are conformably overlain by thin-laminated halite of the Cassidy Lake Formation (Windsor Group; McCutcheon 1981). A similar conformable and gradational depositional contact between the

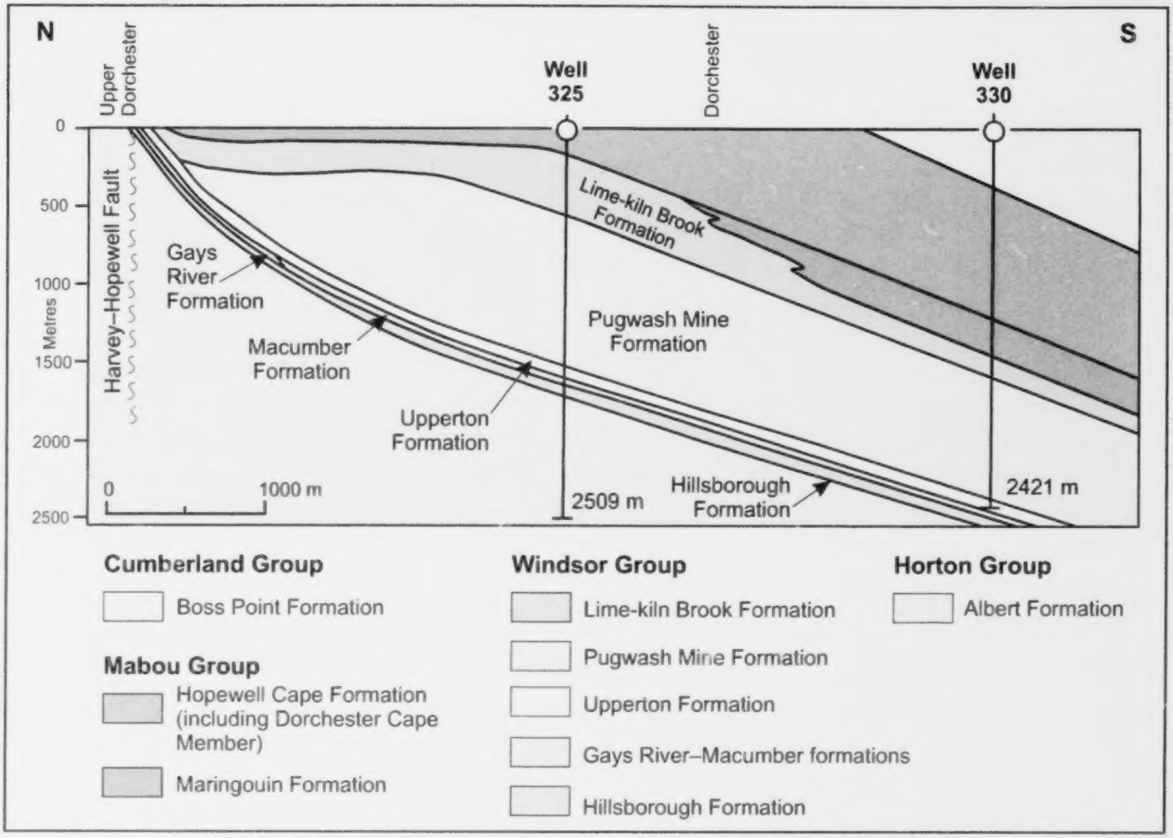

N
S
Upper Dorchester
Well 325
Dorchester
Well 330
0
500
1000
1500
2000
2500
Metres
Harvey–Hopewell Fault
Lime-kiln Brook Formation
Gays River Formation
Pugwash Mine Formation
Macumber Formation
Upperton Formation
0
1000 m
2509 m
Hillsborough Formation
2421 m
Cumberland Group
Boss Point Formation
Mabou Group
Hopewell Cape Formation (including Dorchester Cape Member)
Maringouin Formation
Windsor Group
Lime-kiln Brook Formation
Pugwash Mine Formation
Upperton Formation
Gays River–Macumber formations
Hillsborough Formation
Horton Group
Albert Formation

Figure 32. Cross-section between Upper Dorchester and just south of Dorchester (Plate 4). Section shows 1) interpreted facies relationship between clastics of the Maringouin Formation and sulphates of the Lime-kiln Brook Formation, and 2) 'near-surface' dissolution of salt of the Pugwash Mine Formation and consequent collapse of the Lime-kiln Brook sulphates and the Hopewell Cape conglomerates.

Upperton and Cassidy Lakes Formation is recorded (Anderle et al. 1979, p. 39) in borehole data from the Marchbank Syncline between Upperton and the Clover Hill Fault (Fig. 6).

The Upperton Formation is interpreted to be conformably succeeded by the Pugwash Mine Formation in the subsurface of the Sackville Subbasin (Fig. 32, 33). The contact relationship is in part inferred from a concordant contact interpreted between the basal anhydrite of the Windsor Group and the overlying Pugwash Mine Formation in the adjacent Cumberland Subbasin of Nova Scotia (Ryan and Boehner 1994). Interpretations of seismic reflection profiles (Martel 1987) also suggest a concordant contact between Upperton sulphate and Pugwash Mine salt in the Sackville Subbasin.

Near the paleodepositional margin of the Moncton Subbasin, the Upperton is unconformably succeeded by the Hopewell Cape Formation. For example, at the Peekaboo Corner reference section, McCutcheon (1981, his Fig. A5-5) notes an angular unconformity between the Upperton sulphate and overlying fine-grained redbeds of the Hopewell Group (Mabou Group of current usage).

At Wilson Brook, the eastern boundary of the Upperton Formation is defined by an unconformity with the overlying Hopewell Cape Formation (Plate 4). This interpretation is demonstrated by the divergence in strike of the two formations and is based on the following factors.

- The late Windsor formations that typically overlie the Upperton Formation (e.g., the Pugwash Mine and Lime-kiln Brook formations in the Sackville and Cumberland subbasins) are missing on the Caledonia Uplift block (Fig. 9).
- The Hopewell Cape Formation is several times thinner where it overlies the Caledonia Uplift than it is in the Sackville and Cumberland subbasins. The condensed Hopewell Cape section suggests that the lower part of the formation was never deposited on the uplifted Caledonia block.
- The lenses of limestone-clast conglomerates and finer clastics in the Upperton gypsum are interpreted as subterranean cavern-fill deposits (see below). Such an interpretation requires the 'deep-water' marine Upperton rocks to have been exposed before deposition of the terrestrial Hopewell Cape rocks.

At Gray Brook, the southern boundary of the Upperton Formation is defined by an unconformable contact with the Hopewell Cape Formation (Plate 4). The exposed contact in an abandoned gypsum quarry provides convincing evidence of two periods of karstification of the Upperton Formation. The first karstification was a post-Upperton but pre-Hopewell Cape event, as indicated by a relief of 10 m to 15 m between the tops of knobs (paleostacks) and the bottoms of adjacent sinkholes in the Upperton gypsum. The sinkholes are filled with reddish brown mudstone and lesser granular sandstone and conglomerate, lithotypes similar to those of the overlying Hopewell Cape Formation. Bedding in the sinkhole-filling strata is definitely discordant with the walls of the sinkholes but is concordant with beds in the Hopewell Cape Formation above the stacks.

The second karstification took place after Hopewell Cape lithification. This is demonstrated by a 'structural contact' in redbeds in one of the sinkholes, in which gently dipping, reddish brown mudstone of the early fill succession abuts a narrow crumpled zone of steeply dipping, reddish brown mudstone and granular sandstone. The brittle nature of fractures in the crumpled mudstone suggests that the 'slumping' and subsequent collapse of the now steeply dipping redbeds took place after lithification. The timing of the second karstification is unclear. For example, the structural contact between the early, gently dipping beds and the later, steeply dipping collapsed beds is not exposed upsection above the quarry face. The later karstification may not have occurred until the Holocene.

Lateral Facies Relationships: McCutcheon (1981) notes gypsum porphyroblasts 9 m below the upper contact of the Gays River Formation in the Peekaboo Corner area and, on this basis, suggests that the "deep-water" Upperton Formation (see below) is in part a lateral equivalent of the shallow-water Gays River algal buildups. McCutcheon (1981, his Fig. 3-1a) also uses borehole records from Peekaboo Corner to demonstrate that the Gays River Formation locally oversteps the Upperton Formation, adding support to the interpretation of lateral facies equivalency.

The Upperton Formation is interpreted to be in part laterally equivalent to the higher order chloride salts (halite and sylvinite) of the Cassidy Lake Formation in the southwestern part of the Moncton Subbasin (McCutcheon 1981, his Fig. 3-1). This is suggested by the fact that the two formations are vertically gradational; therefore, according to Walther's Law, they may be (although, for evaporites, not necessarily are) laterally gradational (James and Kendall 1992). The contact between the Upperton Formation and the overlying Pugwash Mine Formation in the subsurface of the Sackville Subbasin is interpreted to be conformable. The consistent thicknesses of the Upperton and Pugwash Mine formations between Wells 325 and 330 near Upper Dorchester imply that the formations are depositionally continuous and that no section has been omitted (Fig. 32, 33).

The limestone-clast conglomerates and fine-grained redbeds at the base of and within sulphates of the Upperton Formation in the Curryville and Wilson Brook areas indicate that a significant karstification event took place along the margins of the basin in Windsor time. The event probably coincided in large part with the lowstand indicated by the high-order sodium and potassium chlorides of the Cassidy Lake and Pugwash Mine formations. Caverns that formed during karstification of the exposed Upperton Formation appear to have infilled later with terrestrial deposits, as represented by the lenticular bodies of limestone-clast conglomerates and finer grained redbeds in the sulphates. The absence of post-Windsor clasts such as lithotypes of the Mabou or Cumberland groups also implies an early cavern-fill event.

Depositional Environment: The Upperton Formation appears to have been deposited in relatively deep water of unknown depth. Evidence of the environment of deposition is somewhat obscured by diagenesis and epigenesis (see above). In the southwestern Moncton Subbasin, host rocks of the Upperton Formation are in large part thinly parallel-laminated wackestone and packstone (McCutcheon 1981). Laminated gypsum (primary?) and anhydrite occur along Wilson Brook (Fig. 31) (McCutcheon 1981, his Fig. 3-25; Sund 1958, his Plates IIB and VII). Thin-laminated carbonates and sulphates are a key indicator of deep-water evaporite deposition (Kendall 1992, p. 395). The laminated host carbonates are also organic-bearing, which implies anoxic bottom conditions and a water column deep enough to have been stratified (Kendall 1992). The general absence of sand-size clastic debris also indirectly suggests an environment removed from the terrigenous hinterland. Enterolithic (slump) folds, a convincing indicator of basin relief and depth (Kendall 1992), have not been reported from the Upperton Formation. However, this is not surprising, considering the degree of postdepositional replacement of the host rock carbonates and siliciclastics.

Is the thin 'redbed' unit at the base of the Upperton Formation in the Gray Brook and Wilson Brook areas continental or marine? If the unit is in depositional continuity with the underlying Macumber limestone and the overlying Upperton sulphates (i.e., not a late karst cavern-fill deposit), it is with near certainty a marine unit. This interpretation follows from arguments set forth for the environments of deposition of the underlying Macumber limestone and the overlying Upperton sulphate (see McCutcheon (1981) and elsewhere in this report). The Macumber and Upperton formations are deep-water marine successions. It thus contravenes Walther's Law to have a continental redbed unit lie between them without the redbeds being bounded below and above by shallow-water marine clastics or carbonates. Such shallow-water beds do not exist here. Also, no evidence has been found in the report area or elsewhere in the Moncton Subbasin of a unit or tongue of terrestrial redbeds in the shallow-water marine carbonates of the Gays River Formation. Furthermore, it is unlikely that red sediment with an 'inherited' red colour bypassed the shelf to be deposited downslope in deeper water. The red coloration of these beds is therefore interpreted to be the result of postlithification exposure and oxidation that took place during or after the Carboniferous. The postlithification reddening occurs consistently in the area with the commonly noted red or reddish brown colour overprinting the typical grey or black Macumber limestone (Hamilton 1965, p. 67; McCutcheon 1981, p. 62).

McCutcheon (1981) used lithological descriptions by McLeod (1980) to interpret the limestone-clast conglomerates and associated fine-grained redbeds in the Upperton Formation as post-sulphate cavern-fill deposits. He based his conclusion on the apparent contradiction to Walther's Law, of having tongues of terrestrial redbeds lying in depositional continuity with deep-water marine sulphates. He argued that the only plausible explanation for the spatial association was that the red, mud-matrix, limestone-clast conglomerates must postdate the Upperton sulphates. McCutcheon's thesis is supported herein, and the conglomerates are interpreted as fluvial sediments deposited by subterranean rivers. The lowermost lens of limestone-clast conglomerates and redbeds in the Curryville boreholes (McLeod 1980, his Fig. 7) overlies limestone of the Macumber Formation. The Macumber limestone in one hole is less than half the thickness of limestone in adjacent holes. This suggests that the conglomerates and redbeds are in erosional contact with the underlying limestone, explaining the source of the clasts. Such an interpretation is consistent with the proposed cavern-fill environment of deposition cited above.

Age: No age is assignable to the few foraminifera and ostracods reported from the Upperton Formation. The formation has been given a middle Visean age on the basis of miospore assemblages in the underlying Gays River and Parleeville formations and overlying Cassidy Lake Formation. All of these formations have been placed in assemblage Zone 1 (the NS Miospore Zone (Fig. 15) on the basis of ages obtained from spores collected by S.R. McCutcheon and M.J. McLeod from southern New Brunswick sites beyond the report area. The miospore assemblage dates were provided in written communications to McLeod and McCutcheon by Barss (1979a, 1979b) and to McCutcheon by Utting (1979).

Relationship to Previous Stratigraphy: The name 'Upperton' was introduced by Anderle et al. (1979) to describe an upper, anhydrite-dominated member of the Upham Formation near Upperton (Fig. 6). McCutcheon (1981) elevated the Upperton Member to the Upperton Formation, and the name 'Upham Formation' was abandoned. The Upperton Formation as used herein follows that originally defined by McCutcheon (1981). In the current report area it is synonymous with 1) Zone 4 of the Hillsborough Series of Wright (1922), 2) the gypsum and anhydrite unit of the Windsor Series of Norman (1941a), 3) the massive gypsum unit **Mwg** of the Windsor Group of Gussow (1953), and unit 7b of the Windsor Group of McLeod (1980).

Pugwash Mine Formation

Author: Carter (1990).

Type Section: Carter (1990) describes a composite type section from subsurface workings and drill core at the Pugwash salt mine near Pugwash in Cumberland County, Nova Scotia (NTS 11 E/13; Fig. 7). The section lies in the Cumberland Subbasin of Nova Scotia.

Reference Sections: A reference section for the Pugwash Mine Formation in Nova Scotia is in Pacific Fox Harbour drillhole C-96V, 12 km east of Pugwash (Fig. 7; see summary litholog *in* Ryan and Boehner 1994). A good reference section in New Brunswick appears in Well 330 (depth interval 1576–2371 m; Fig. 32, 33). The well was drilled in 1960 and is situated 1.8 km south of Dorchester, Westmorland County (NTS 21 H/15; Plate 4), in the northwestern corner of the Sackville Subbasin.

Definition and Description: The name 'Pugwash Mine Formation' has not previously been used in New Brunswick. It is applied herein to define a unit that overlies the Upperton Formation and that comprises marine rock salt, minor interstratal anhydrite and fine-grained clastics, and rare dolostone. In the Sackville and Cumberland subbasins in New Brunswick (Fig. 6, 7), the Pugwash Mine Formation is overlain by interstratified marine carbonates, evaporites, and continental clastics that are correlated with the Lime-kiln Brook Formation of the Cumberland Subbasin in Nova Scotia. The Pugwash Mine Formation is not exposed on surface in New Brunswick. Instead, lithological data for the formation consist of well cuttings from Well 325, cuttings and core from Well 330, core from Well 711, and cuttings from Well 716; all four wells are located in the Sackville Subbasin (Plates 4, 5).

Well 325 is situated about 1 km north of Dorchester (Fig. 32). The well litholog indicates that the Pugwash Mine Formation (depth interval 543–1520 m) is composed nearly entirely of colourless to white rock salt with only minor crystals and thin stringers of selenite. Cuttings from the well, selected over intervals totalling 27.4 m, yield the following analyses in wt %: 54.43% Cl, 34.75% Na, 3.92% SO_4, 2.63% CaO, nil K, and 0.99% insolubles (Hamilton 1961a).

Well 330 (Fig. 32, 33) lies 1.8 km south and downdip of Well 325 and contains the more lithologically varied section of Pugwash Mine Formation. Accordingly, Well 330 is selected herein as a reference section for the formation in New Brunswick. Its litholog shows three significant intervals in which the rock salt is fairly free of impurities (Fig. 33). Most of the remainder of the section has greater than 5% siliciclastics and/or anhydrite and rare dolostone. The siliciclastics are predominantly red or reddish brown shale with minor accompanying grey shale and very rare grey and reddish brown sandstone. The shale commonly contains rock salt crystals of syndepositional or diagenetic origin.

Three cores were taken from the formation in Well 330 (Fig. 33). The upper core (depth interval 1578.0–1582.6 m) was mainly rock salt with thin beds of red and grey shale. The medial core (1948.8–1951.8 m) recovered 2.64 m of massive fine- to medium-grained anhydrite containing irregular fillings (veins?) of rock salt up to 5 cm long and 2.5 cm wide. The lower core (2353.7–2355.8 m) also cut massive anhydrite with about 10% irregular fillings of clear rock salt.

Well 711 is located 2 km northeast of Woodhurst and is a cored hole drilled on the same well pad as Well 716 (Plate 5). The company litholog for Well 711 is brief but records a 177 m thick section (depth interval 1964–2141 m) dominated by rock salt. The cored interval is interpreted as the Pugwash Mine Formation. The log cites 143 m of clear and minor pink and orange rock salt, 19 m of grey anhydrite near the unit base, 13 m of red claystone breccia cemented by orange rock salt (2063–2076 m), and 2 m of greyish green, laminated shale immediately above the claystone breccia.

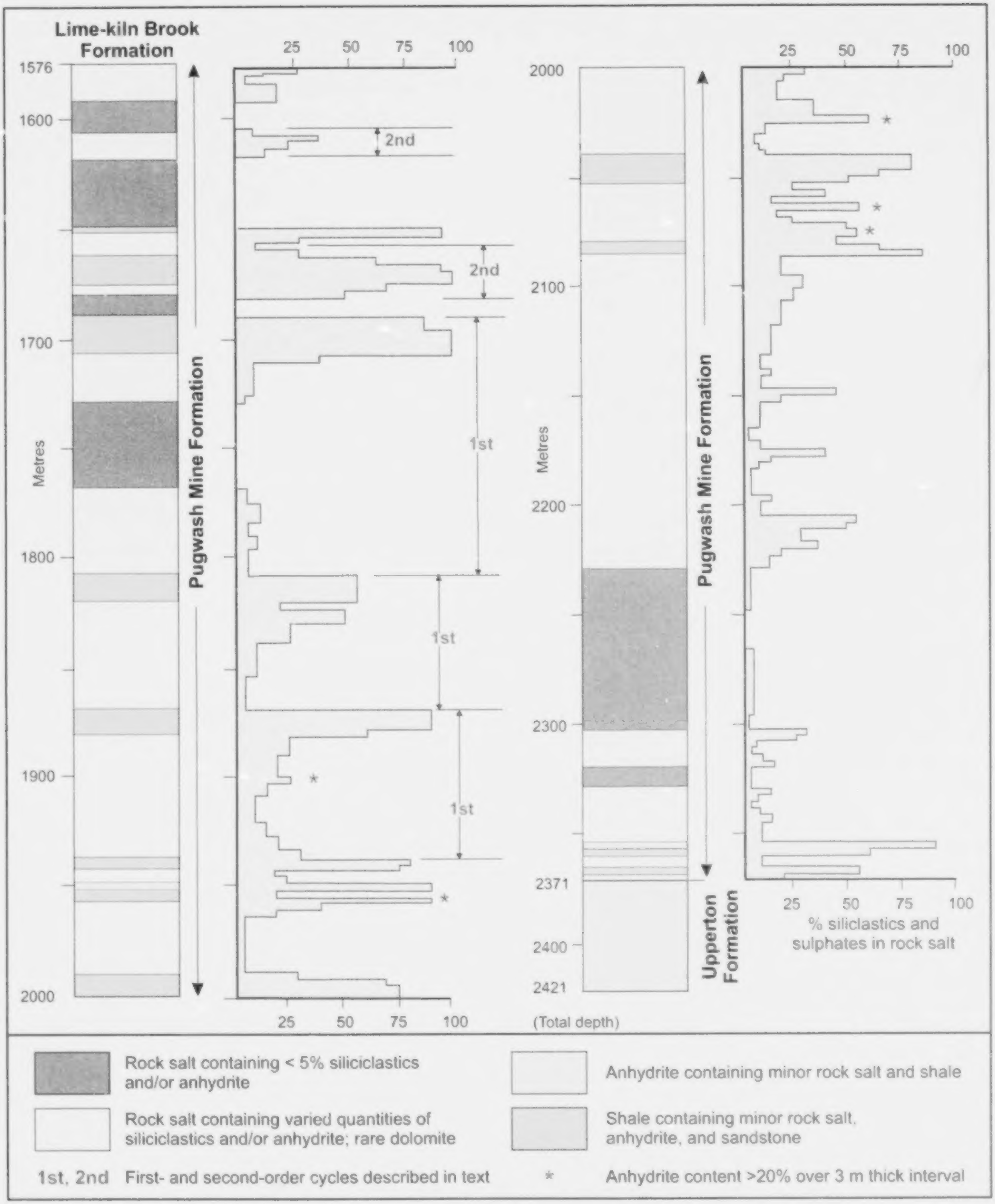


Figure 33. Graphic litholog and histogram showing visually estimated percentage of siliciclastics and sulphates in rock salt of the Pugwash Mine Formation at its reference section in Well 330 (see Fig. 32). Rock salt that is relatively free of impurities occurs at depth intervals 1615–1649 m, 1729–1768 m, and 2229–2301 m.

Lithological details for the Pugwash Mine Formation in Nova Scotia are given by Evans (1972), Carter (1987), and Ryan and Boehner (1994), and are based mainly on observations from mines at Pugwash and Napan in the Cumberland Subbasin. Carter (1987) ascertains the original stratigraphy of the complexly deformed Pugwash diapir on the basis of identifying distinctive anhydrite units. Howie (1986) contains excellent photographs of primary (?) bedding in the rock salt and anhydrite in the Pugwash mine as well as descriptions and figures showing the mine's complex folds and post-fold conjugate fractures.

Distribution and Thickness: The Pugwash Mine Formation appears in the subsurface in the Sackville and Cumberland subbasins. The exact distribution and regional variation in thickness is imperfectly known. Martel (1987) used 15 seismic reflection lines in the Sackville Subbasin to interpret the distribution of the Windsor Group. From this data it is apparent that the group shows a considerable variation in thickness, perhaps due largely to postdepositional flowage of salt of the Pugwash Mine Formation. Martel (1987) notes the existence of northeast-trending salt ridges at Aulac (the 'Tantramar Salt Ridge') and Middle Sackville (Plate 5). He also reports an arch between the two ridges and demonstrates that the Windsor Group, including the Pugwash Mine Formation, pinches out or onlaps against that arch.

Thickness variations in the salt of the Pugwash Mine Formation are also indicated by regional gravity data. Gussow (1953, p. 1798–99), Chandra et al. (1982), and Hassan (2000) produced gravity maps of the Sackville Subbasin and note a linear negative gravity anomaly or series of anomalies extending along the north side of the Wood Creek Fault from Johnson Creek northeastward to Aulac (Fig. 3). From there, an anomaly extends northeast along Fort Cumberland Ridge and lies approximately below the surface trace of the Tantramar Fault (Plate 5). Gussow (1953) also shows a gravity minimum in the Middle Sackville area, which implies the presence of salt and corroborates Martel's (1987) aforementioned seismic reflection evidence.

In the northwestern corner of the Sackville Subbasin, Well 325 intersected 977 m of relatively clean rock salt of the Pugwash Mine Formation. The nearby Well 330 cut 795 m of rock salt and minor anhydrite and shale of the formation (Fig. 32, 33). The grossly similar thicknesses of the formation in both wells suggest a tabular-shaped salt body in this area and not a domal structure centred near Well 325, as was previously interpreted (Gussow 1953; Hamilton 1961a; Martel 1987). The total section thickness of the Pugwash Mine Formation in Well 711 is only 177 m, which is less than 25% of the apparent thickness of the formation in Wells 325 and 330. This could imply that a major part of the formation is absent (eroded) in Well 711 or that the sections in Wells 325 and 330 are anomalously thick due to halokinesis.

In the Cumberland Subbasin in New Brunswick, the only subsurface evidence of the formation is a linear, east–west-trending gravity low on the southern part of Maringouin Peninsula (Gussow 1953; Chandra et al. 1982). The negative anomaly lies directly below surface exposures of the Lime-kiln Brook Formation at Pecks Cove (Plates 4–6) and strongly suggests rock salt in the shallow subsurface. At Pecks Cove, a surface anticline referred to herein as the Maringouin Anticline (Plates 5, 6) may represent in part a halokinetic feature rather than solely a compressive tectonic structure resulting from a rising intrusive mass of Pugwash Mine salt. The Maringouin Anticline (Fig. 6, inset) is the western extension of the Minudie Anticline in the Cumberland Subbasin of Nova Scotia (Ryan and Boehner 1994).

Rock salt is extracted from a diapir of the formation in the core of the Minudie Anticline at Napan. Howie and Barss (1975) estimate structural thicknesses of up to 6000 m for salt in diapirs in the Cumberland Subbasin (Ryan and Boehner 1994). (See discussion of the Maringouin Anticline under ***Dennis Beach Fault*** and ***Lockhart Lake Fault*** in Chapter 3.)

Lower and Upper Boundaries: The lower boundary of the Pugwash Mine Formation is interpreted to be conformable and gradational with the underlying Upperton Formation. Martel (1987) notes concordance in seismic reflectors within the Windsor Group in the Sackville Subbasin. The gradational nature of the boundary is inferred from cuttings in Wells 325 and 330. Near the boundary, minor beds of anhydrite occur in the Pugwash Mine Formation and minor rock salt layers appear in the underlying Upperton Formation. In Well 711 the contact between the Pugwash Mine and Upperton formations is placed at a depth of 2141 m, marking the base of the lowest clean salt interval in the well. The presence of an anhydrite bed above the contact (depth interval 2106–2125 m) implies that the two formations are depositionally continuous. The lower boundary of the Pugwash Mine Formation is neither exposed nor intersected in boreholes in the Cumberland Subbasin of New Brunswick or Nova Scotia (Ryan and Boehner 1994, p. 15).

The upper boundary of the Pugwash Mine Formation is interpreted to be concordant with the Lime-kiln Brook Formation in the central part of the Sackville Subbasin. Seismic profiles for the subbasin (Martel 1987, and profiles available from NBDNR offices) suggest a concordant succession through beds of the Windsor Group in the axial part of the subbasin. A gradational boundary between the Pugwash Mine and Lime-kiln Brook formations is suggested by cuttings in Wells 325 and 330 (Fig. 32), which show minor rock salt in the lower sulphates of the Lime-kiln Brook Formation and selenite crystals in the upper salt beds of the Pugwash Mine Formation. The upper boundary of the Pugwash Mine Formation in Well 325 is defined as the top of the uppermost significant rock salt bed at a depth of 543 m.

In Well 711 the upper contact of the Pugwash Mine Formation is assigned a depth of 1964 m (sub-Kelly). That contact marks the boundary between the uppermost clean interval of rock salt of the Pugwash Mine Formation (1964–2015 m) and an overlying interval (1932–1964 m) of grey laminated shale and minor associated red shale containing vugs filled with orange salt. The shale, fine-grained clastics, and associated overlying (1085–1064 m) minor salt and anhydrite are correlated with the Lime-kiln Brook Formation. The Pugwash Mine–Lime-kiln Brook formational contact as assigned herein in Well 711 may represent an erosional boundary. The authors have not studied the core from the well to confirm this interpretation, but the contrast in thickness of the Pugwash Mine Formation between Well 711 (177 m) and Wells 330 (795 m) and 325 (977 m) strongly suggests that Pugwash Mine strata are missing in the area of Well 711. Martel (1987, his Fig. 3) noted a convergence of reflectors ascribed to the Windsor Group just south of the Dorchester Fault in the Coppermine Hill area near Well 711, supporting the conclusion that part of the Windsor section is likely omitted in the updip part of the group adjacent to the Dorchester Fault. It is suggested here that rock salt, being the most soluble evaporite, is the lithology most susceptible to removal.

In New Brunswick the upper contact of the Pugwash Mine Formation with the Lime-kiln Brook Formation appears to have been suberoded between a point about 1 km north of Well 325 and continuing updip from there to the northern subsurface extent of the Pugwash Mine

Formation. This interpretation is based on the remarkably abrupt thinning of the Pugwash Mine Formation that is inferred north of Well 325 (Fig. 32). Geometrical constraints arising from formational picks in Wells 325 and 330, and from the surface geology at Upper Dorchester, indicate that the Pugwash Mine–Lime-kiln Brook contact lies approximately parallel to surface in this area. In this regard, the interval of 250 m to 300 m below surface seems a reasonable depth to encounter the present fresh water–salt water boundary. About 10 km northeast of Well 325 and immediately south of the Dorchester Fault, Martel (1987, his Fig. 3) notes an analogous thinning of the Windsor Group, on the basis of converging interpreted time-depths of the basal and top Windsor seismic reflectors. Again, the late Windsor reflector in that area is roughly parallel to surface but at a depth of about 2 km.

The Pugwash Mine Formation is interpreted to have been completely suberoded near Upper Dorchester (Fig. 32), where Canadian Merrill Ltd. drilled Wells 369 to 376 in 1971 while exploring a barite–celestite occurrence (Plate 4) immediately south of the Dorchester Fault. The cores indicate an aggregate thickness for the Windsor sulphates of greater than 160 m, two to four times the known local thickness of the basal Windsor sulphates of the Upperton Formation as estimated by Hamilton and Barnett (1970) and McLeod (1980). These data suggest that the Lime-kiln Brook sulphates and carbonates collapsed onto the Upperton sulphates in the Upper Dorchester area, a result of the previously intervening salt of the Pugwash Mine Formation having been removed (St. Peter 2001, his Fig. 4e, 4f).

Ryan and Boehner (1994, p. 15) describe the upper contact of the Pugwash Mine Formation in the Cumberland Subbasin of Nova Scotia as "problematical due to the disrupted relationship with overlying fault-intruded strata." Consequently, the character of the original Pugwash Mine–Lime-kiln Brook boundary in Nova Scotia is uncertain, given the presently available data (R.C. Boehner, pers. comm. to CSP, 1998). Ryan and Boehner (1994) also note a conflict concerning the location of the formational boundary in the Nova Scotian reference section in Pacific Fox Harbour drillhole C-96V. For example, it is unclear whether a thick (200–300 m) sequence of redbeds below the lowest carbonate interval in the well is included in the Pugwash Mine or Lime-kiln Brook formation. Boehner (pers. comm. to CSP, 1998) explained that considerable ambiguity existed in 1994 and continues to exist about where to place the Pugwash Mine–Lime-kiln Brook contact in the well. In fact he thought it possible to assign the entire well section to the Lime-kiln Brook Formation, rendering the Pugwash Mine Formation entirely absent there. The Pacific Fox Harbour drillhole C-96V in Nova Scotia thus seems to be an unfortunate choice as a reference section for the upper boundary of the Pugwash Mine Formation. A better choice may be Well 330 in New Brunswick, where the boundary is placed at the top of the uppermost significant bed of rock salt that lies above a thick section dominated by rock salt (Fig. 33).

Giles (1981) uses lithological evidence to postulate a hiatus between major transgressive–regressive Cycle 1 and Cycle 2 in many sections of the Windsor Group in Nova Scotia. In the Cumberland Subbasin of Nova Scotia and, by correlation, in the Sackville Subbasin (Fig. 6), the Cycle 1–Cycle 2 boundary lies between the Pugwash Mine and Lime-kiln Brook formations (Ryan and Boehner 1994, their Fig. 2-4). A compilation and interpretation of available biostratigraphic data (conodonts, foraminifera, and miospores) in the Windsor Group of Nova Scotia and the correlated Codroy Group of Newfoundland equivocally support the existence of a hiatus at the Cycle 1–Cycle 2 boundary (von Bitter et al. 2007).

Lateral Facies Relationships: The only lithological control on the Pugwash Mine Formation in New Brunswick is from four wells in the Sackville Subbasin. Wells 711 and 716 are twinned core and rotary-drilled wells and therefore yield essentially a single dataset. In Well 325 the formation contains relatively clean halite, whereas in Well 330 to the south it reveals many interbeds of fine-grained siliciclastics and sulphates. If the siliciclastics are terrestrial, the area around Well 325 in the Sackville Subbasin could be interpreted as a deeper, more offshore part of the local basin and the area around Well 330 as more hinterland. Supporting this interpretation is the apparent lateral intertonguing of the terrestrial Maringouin Formation in Well 330 with sulphates of the largely marine Lime-kiln Brook Formation in Well 325 (Fig. 32).

In the western Moncton Subbasin, chlorides of the Cassidy Lake Formation conformably overlie sulphates of the Upperton Formation (McCutcheon 1981). They accordingly occupy a stratigraphic position analogous to chlorides of the Pugwash Mine Formation in the Sackville Subbasin. The Cassidy Lake Formation consists mostly of rock salt but also contains thick minable beds of potash-bearing chlorides (mainly sylvinite) in the medial part of the formation (Anderle et al. 1979). This could suggest that, somewhere in the Sackville and Cumberland subbasins, the Pugwash Mine rock salt may also contain potash salts.

Depositional Environment: "Environments that may result in deposition of evaporites occur in a sedimentary continuum that begins in the subaerial continental environment and extends into a hypersaline sea...." This quote from Schreiber et al. (1977, p. 169) underscores the variety of environments wherein precipitates of common carbonates, sulphates, and chloride minerals can form. Briefly, those environments include 1) continental playas and perennial saline lakes, 2) coastal sabkhas and ephemeral to perennial salinas, and 3) marine-restricted shelves and basin-centre settings (Kendall 1992). The basin-centre evaporites are further subdivided into three types: a) shallow-water–shallow-basin, b) shallow-water–deep-basin, and 3) deep-water–deep-basin. No present-day analogues exist from which to model the giant marine evaporite basins that are known from the rock record (Reading 1978) and have been variously ascribed to deep basinal or widespread shallow-marine settings (Kendall 1992).

The success of properly interpreting the depositional environment of any given evaporite sequence depends largely on the preservation of bedforms, primary sedimentary structures, and early diagenetic features (Schreiber et al. 1976, 1977; Kendall 1992). Displacive or replacive anhydrite nodules, for instance, are characteristic of but not exclusively restricted to continental and coastal sabkhas. The chevron calcite texture results from successive flooding events typical of sabkhas (Reading 1978). Algal laminates and stromatolites are restricted to peritidal environments from lower supratidal to photic zone subtidal (Logan et al. 1964). Halite tepee structures are typical of episodically drying-out hypersaline lakes and hypersaline marine lagoons that are perennially under water (Sonnenfeld 1984). Deep-basin sulphates and chlorides contain persistent, even millimetre-scale, parallel laminations. Those without diagenetic or later textural overprinting may contain evidence of debris-flow or turbidity-current deposits (Kendall 1992).

The well cuttings from Wells 325, 330, and 711 obviously offer no evidence of bedforms or other primary structural or textural evidence to aid in interpreting the depositional environment. The authors have not studied the core from Well 711, and the company litholog is too brief to offer much assistance (although the logged rare "dark coloured bands" could be primary cyclic laminations). Hence, the only available criteria for interpreting the depositional environment of the Pugwash Mine Formation in New Brunswick are the association of rock types and the nature of the cyclicity of those lithotypes.

The litholog for Well 325 shows a close spatial association of the minor red shale and anhydrite in the Pugwash Mine Formation (Fig. 33). The redbeds almost certainly were deposited in an oxidizing environment and thus represent terrestrial or perhaps supratidal siliciclastic mudflat deposits. This suggests that the associated and interbedded sulphates are early diagenetic continental or coastal sabkha or intertidal deposits. If so, the depositional environment for the non-chlorides in the formation would be satisfactorily explained by the cyclic carbonate–sulphate–redbed coastal sabkha model proposed by Schenk (1969, 1984) for similar exposed cyclical sequences in the Windsor Group of Nova Scotia.

Schenk's (1969, 1984) coastal sabkha model provides a plausible interpretation for the depositional environment of those cycles but does not adequately explain the presence of thick halite intervals in the Pugwash Mine Formation. For example, fairly clean, siliciclastic-free, halite sequences greater than 200 m thick such as occur in Well 330 (Fig. 33) have not been recorded, to the present authors' knowledge, as displacive or replacive deposits in known or interpreted coastal sabkha settings. Surely a restricted hypersaline standing body of water is required to suitably account for the thick halite intervals in the formation. This is particularly true if the 977 m of thick clean salt in Well 325 is any reflection of the depositional thickness of the formation. The close spatial association of thick marine halite intervals and thin tongues of terrestrial redbeds implies that the salt was deposited relatively close to the paleostrand.

Was the hypersaline body of water that generated the Pugwash Mine halite in the Sackville Subbasin a shallow-water, restricted-circulation lagoon (or series of lagoons) situated around the perimeter of the subbasin behind a shelf-edge barrier? Or was it a basin-wide water body with restricted circulation and hypersaline conditions but lacking a shelf-edge barrier? Scenario 2 is more likely. Halite has a widespread geographic distribution in the central part of the Sackville Subbasin, indicating that salt distribution was not isolated to a linear shelf-margin belt around the basin perimeter, just basinward of the bounding escarpments of the Harvey–Hopewell, Dorchester, Port Elgin and Wood Creek faults (Fig. 6, 8).

A similar basin-centre distribution of thick chlorides appears in other subbasins of the Maritimes Basin. Halite and potash salts of the Cassidy Lake Formation occur in the axial part of the Marchbank Syncline southwest of Sussex (Anderle et al. 1979; McCutcheon 1981); thick halite of the Stewiacke Formation is found in the central part of the Shubenacadie Basin in central Nova Scotia (Boehner 1984). Howie (1986) describes the distribution of Windsor salt in the Cumberland Subbasin of Nova Scotia. In all cases, the chlorides occur in the centre of the subbasins as a 'bull's eye' lithofacies surrounded by less soluble sulphates, carbonates, and ultimately terrestrial clastics on the perimeter of the various subbasins.

A close analogue of the redbeds–sulphate–chlorides facies architecture of the Pugwash Mine Formation in the Sackville Subbasin and similar thick chloride facies in other subbasins of the Maritimes Basin is offered by the Quaternary potash-bearing evaporites in the Danakil Basin (Afar Depression) of Ethiopia (Holwerda and Hutchinson 1968). The Afar Depression was initiated and is still forming as a result of rifting or transtension between the African and Arabian plates (Windley 1982, p. 234). Maximum subsidence along the rift zone resulted in an asymmetric basin and the syntectonic accumulation of nearly 1 km of evaporites. The marine halite and associated potash salts occur just off the escarpment on the faulted western and deepest part of the Danakil Basin (Holwerda and Hutchinson 1968). As in the subbasins of the Maritimes Basin, the chlorides in the Danakil Basin are surrounded by less soluble sulphates of gypsum and anhydrite. The Danakil sulphates give way to alluvial outwash muds and proximal gravels on the western escarpment side and intertongue with terrestrial outwash mud on the eastern hinged margin. Thus, a Quaternary marine invasion of the tectonically active Danakil Basin, possibly via a connection with the Red Sea, resulted in an intertonguing of transgressive marine and regressive (dominantly) terrestrial strata. The similarities in tectonic setting and lithofacies architecture between the Quaternary Afar Depression and the Windsor evaporites of the subbasins of the Maritimes Basin are quite compelling.

An obvious cyclicity appears in the alternation of rock salt–anhydrite–shale in the Pugwash Formation at Well 330. The well litholog shows two distinct orders of cyclicity (Fig. 33). The first-order cycles range from 60 m to 150 m thick. They are mainly asymmetrical and show a gradual increase, followed by a very abrupt drop, in shale content. Note how the shale content in Figure 33 rises gradually from 1920 m to 1869 m, at which depth the content drops to about 5%, followed by another gradual increase to a depth of 1808 m, above which the shale content sharply falls again. The asymmetric cycles are interpreted to reflect a gradual upward-shallowing or regression from deeper water beds of rock salt to supratidal mudflat deposits. The regressive part of most cycles was followed by a rapid return to clean rock salt, presumably coincident with a sudden transgression and a deepened water column. This may have resulted from a sudden eustatic sea level rise, renewed accelerated subsidence, or a combination of both environmental shifts.

The second-order cycles of alternating rock salt–anhydrite–shale range from 2 m to 15 m thick and are superimposed on the first-order cycles. These cycles are predominantly symmetrical and demonstrate a progressive increase and decrease in the quantity of shale and anhydrite within the rock salt. Two examples of the second cycles are given by shale peaks at depths of 1610 m and 1670 m (Fig. 33). These cycles may reflect a higher frequency of regressive–transgressive alternation or simply may indicate an enhanced supply of terrestrial detritus being deposited in a continually subaqueous environment.

Age: No spores, microfauna, or macrofauna are recorded from the Pugwash Mine Formation in New Brunswick. Ryan and Boehner (1994) report an age of early to middle Visean from spores collected in the Cumberland Subbasin of Nova Scotia and dated by Dolby (1989).

Relationship to Previous Stratigraphy: Gussow (1953, p. 1745) recorded the presence of rock salt in Well 325 under his thickness of Windsor Subzone B but did not assign the salt to Subzone B or allude to its stratigraphic position in that subzone. However, on his cross-section U–V (Gussow 1953, p. 1793), he placed the salt above the basal Windsor sulphates (Upperton Formation), suggesting that the Dorchester salt was diapiric into the bounding Maringouin Formation. McCutcheon (1981) did not describe the lithology or stratigraphy of the rock salt (Pugwash Mine Formation) in the Sackville Subbasin. On his summary paleogeographic diagram (his Fig. 4-2a), he placed the Pugwash salt in Subzone A, the basal zone of the Windsor Group (Bell 1929). Ryan and Boehner (1994, their Fig. 2-4) assigned the Pugwash Mine Formation in the Cumberland Subbasin of Nova Scotia to the basal cycle of the Windsor Group, Cycle 1 of Giles (1981) and von Bitter et al. (2007).

Lime-kiln Brook Formation

Authors: Ryan and Boehner (1994).

Type Section: The type section is the Lime-kiln Brook quarry and contiguous outcrops along Lime-kiln Brook near Napan in Cumberland County, Nova Scotia (NTS 21 H/16; Fig. 6).

Reference Sections: No completely exposed section of the Lime-kiln Brook Formation exists in New Brunswick. The section of clastics and overlying carbonates exposed at Lower Cape about 1 km east of the mouth of Demoiselle Creek (NTS 21 H/15; Plate 4) is representative of the upper part of the formation in that area. Small outcrops of gypsum about 2 km northwest of Lower Cape and immediately south of the Harvey–Hopewell Fault are representative of that facies of the formation.

Definition and Description: In the report area, the Lime-kiln Brook Formation represents a succession of alternating tongues of marine and continental strata. The marine beds comprise limestone, anhydrite (gypsum), minor dolostone and halite. The terrestrial tongues include conglomerate and sandstone in basin-margin upland locations, and finer red to locally grey siltstone and shale in marginal marine mudflat environments. The formation conformably underlies the Mabou Group.

The Lime-kiln Brook Formation in New Brunswick occurs only in the Sackville and Cumberland subbasins. Its surface exposures are divisible into three units that correspond to map units **CLK$_{g}$**, **CLK$_{cc}$**, and **CLK$_{ls}$** (Plates 4–6). Well intersections (Wells 325, 330, 711, and 716) in the Sackville Subbasin provide additional lithological complexity and correlation challenges.

Map unit CLK$_{g}$ consists mainly of white to grey, massive to granular and locally marble-textured gypsum and anhydrite, and minor limestone and siliciclastic rocks. It occurs within or adjacent to the Sackville Subbasin in outcrops at Upper Dorchester, Grande Anse, and Lower Cape, and in the subsurface at Dorchester and Beaumont. Within the Cumberland Subbasin, it is exposed at Cape Maringouin, Chemical Creek, Shepody Marsh, and Lockhart Lake.

Dorchester–Upper Dorchester area: A thick unit of anhydrite and gypsum (sulphates) was discovered near Upper Dorchester by Canadian Merrill while drilling shallow holes to outline a barite–celestite prospect. Sinkholes aligned in a northeasterly direction are the only surface evidence of sulphates in this area. The sulphate unit in the drillholes is approximately 160 m thick and concordantly overlies a limestone–conglomerate–sandstone unit that occurs immediately to the northwest. The limestone-bearing unit, which hosts the barite–celestite mineralization, is exposed in a small disused quarry on the east side of Highway 106. St. Peter (2001) gives geological details of the quarry.

The thick gypsum and anhydrite unit was known in the area since at least 1949 when Well 325 was drilled just south of Upper Dorchester (Fig. 32). That well lies 2.5 km south of the sinkholes and intersected 422 m of sulphates. The gypsum occurs in depth interval 121 m to 543 m and, according to company logs, comprises subequal volumes of anhydrite and gypsum with a significant portion of the gypsum being pink to reddish selenite. The thickest selenite interval is nearly 100 m thick; it occurs at the base of the sulphate interval immediately above rock salt of the Pugwash Mine Formation and contains minor rock salt throughout. The only lithological break in the sulphate unit is the interval (367.4–380.2 m) logged by the company as quartz conglomerate. The quartz conglomerate conceivably could be linked to the conglomerate and sandstone associated with limestone beds in the aforementioned small limestone quarry. The thick sulphate unit in Well 325, as at the surface gypsum locality at Upper Dorchester, is overlain by coarse conglomerate and sandstone of the Hopewell Cape Formation (Fig. 32; Plate 4).

The stratigraphic position of this sulphate unit in Well 325 — above rock salt of the Pugwash Mine Formation and below the basal Mabou Group (Hopewell Cape Formation) — suggests its correlation with the Lime-kiln Brook Formation. However, the section is anomalous in that it bears no interstratal marine limestone or terrestrial clastic redbed tongues, features that characterize the Lime-kiln Brook Formation and Cycle 2 units of the Windsor Group regionally (Ryan and Boehner 1994; Giles 1981).

Well 330 lies south of Dorchester, about 2 km south of Well 325 (Fig. 32). The stratigraphic section in Well 330 between 1445 m and 1576 m also lies above rock salt of the Pugwash Mine Formation and below fine-grained redbeds of the Maringouin Formation. The section consists of reddish brown and minor grey shale and siltstone and shows what the company litholog describes as "evidence of salt leaching" throughout. Fine-grained anhydrite appears in the lower 5 m of the unit. As with Well 325, the stratigraphic position indicates correlation with the Lime-kiln Brook Formation, but the lithology is substantially different from the Lime-kiln Brook Formation in outcrops in New Brunswick or Nova Scotia.

Beaumont: Well 706 lies just across Memramcook River from Well 325, about 1 km northeast of Beaumont. The anhydrite unit in Well 706 occurs in depth interval 440 m to 744 m, indicating a unit thickness approaching 300 m. The anhydrite is overlain by 30 m of red mudrocks that may be part of either the Lime-kiln Brook or Maringouin formation. The mudrocks are sharply overlain by coarse conglomerates assignable to the Hopewell Cape Formation. Anomalously, the thick sulphate unit in Well 706 lies west of the Harvey–Hopewell Fault and therefore outside the presently defined boundary of the Sackville Subbasin (Fig. 6; also see description of subbasin boundaries in Chapter 3 under ***Sackville Subbasin Structure***).

The spatial distribution of the thick sulphate unit (i.e., on surface at Upper Dorchester and in Wells 325 and 706) prompts speculation about whether the stratigraphic positions of the sulphates assigned herein to the Upperton Formation at Wilson Brook and in the subsurface at Curryville are completely accurate. As noted above (under ***Upperton Formation***), evidence exists for the extensive subterranean dissolution of sulphates at Curryville. Could this mean that a much thicker unit of Lime-kiln Brook sulphate once existed there — or even perhaps rock salts of the Pugwash Mine Formation?

Grande Anse: Gussow (1953) and Hamilton and Barnett (1970) record a gypsum outcrop on the eastern shore of Shepody Bay, approximately 1.5 km northwest of Grande Anse. The outcrop exposes about 2 m of light grey gypsum cut by selenite veins. The gypsum is in contact to the north with about 1 m of grey limestone. The thickness of the limestone must be only a few metres or tens of metres at most, as it is succeeded farther north (across a 150 m wide concealed interval) by red mudstone and red, cross-laminated siltstone to fine-grained sandstone of the Maringouin Formation. The gypsum and limestone are best assigned to the Lime-kiln Brook Formation, although their stratigraphic position is only tentatively known.

Lower Cape: Small exposures of gypsum lie adjacent to the Harvey–Hopewell Fault northwest of Lower Cape. The gypsum contains porphyroblasts and fractures filled with selenite; it also features lenticular selvages of anhydrite up to 5 cm long and 2 cm wide. These exposures are interpreted as map unit **CLKg**.

Cape Maringouin: Flaherty (1933) notes 30 m of gypsum on the western shore of Maringouin Peninsula about 3 km northeast of Cape Maringouin (Plate 6). Ells (1885, p. 36) reports the gypsum as being much twisted and of uncertain thickness. Hamilton and Barnett (1970, p. 53, and their Fig. 7, 33) also describe the shoreline gypsum as distorted and broken. Flaherty (1933) states the gypsum is overlain by red shale, followed in turn by fossiliferous limestone. The close spatial association of rock types suggests the red shale interval is very thin. The thickness of the exposed part of the fossiliferous limestone is also in dispute. Ells (1885, p. 36) gives a thickness of 40 m, but Gussow (1953) and Hamilton and Barnett (1970) report it as only 3 m thick. The contacts between all three rock types are concealed. Hamilton and Barnett (1970) place the limestone in a separate map unit from the underlying gypsum and shale. The widespread presence of sinkholes (Plate 4) and a few gypsum outcrops (Hamilton and Barnett 1970) north of the gypsum exposure reported by Flaherty suggest that the gypsum interval is likely much thicker than the 30 m he recorded in the shore outcrop. The gypsum interval may be stratigraphically equivalent to the entire section mapped herein as unit **CLKg** on the western side of Shepody Bay. If true, the overlying thin shale and limestone of Flaherty (1933) may be equivalent to the map units **CLKcc** and **CLKls** as defined herein. Future work may warrant this subdivision but, for the present, all exposures of the Windsor Group on Maringouin Peninsula are included here in map unit **CLKg**.

Chemical Creek: Gypsum and anhydrite are exposed in small outcrops and in two disused quarries on the south side of the Harvey–Hopewell Fault at Chemical Creek (Plate 4; see Hamilton and Barnett 1970). The beds dip steeply toward the southeast and comprise white, massive to granular gypsum. The gypsum is obviously secondary and replaces grey, fine-grained and crystalline anhydrite that exists in the gypsum as irregular to subspherical masses up to 1 m in diameter (Hamilton and Barnett 1970).

While assessing the limestone and gypsum resources in southeastern New Brunswick, NBDNR drilled four shallow coreholes in the sulphates at Chemical Creek (Crosby and Waugh 1975). Two holes terminated in overburden, but the remaining two encountered 6 m to 9 m of gypsum near the surface before passing into greater than 30 m of compact microcrystalline anhydrite at the bottom of the holes.

Shepody Marsh: During the same limestone–gypsum assessment program, NBDNR put down three shallow diamond-drill holes on nearby Shepody Marsh where a small gypsum quarry operated about a century ago (Hamilton and Barnett 1970). The holes were drilled, partly on the strength of the former quarry and also on the assumption that the low-lying flats east of Hopewell Hill were likely underlain by gypsum. Shepody No. 32 intersected unconsolidated sand to a depth of 19 m followed by 2 m of limestone; no core was recovered in the bottom 9 m below the limestone. Shepody No. 33 intersected only unconsolidated overburden to a depth of 27 m. Shepody No. 34 cut 13 m of overburden, 6 m of gypsum, 4 m of clay (?), and 2 m of limestone (Crosby and Waugh 1975).

The following description is from a preliminary inspection of the Shepody cores by the authors. In Shepody No. 32, the limestone is mainly medium grey with discontinuous, wispy, dark grey laminae. It has virtually no primary textural features remaining, having undergone diagenetic and later textural modifications. The medium grey fraction (70–80%) comprises silty to fine-grained carbonate grainstone. The dark grey fraction apparently was originally laminae of organic-rich carbonate mudstone or wackestone. These laminae were subsequently 'remobilized' into wispy or irregular lenticules that partly or entirely surround elliptical to irregular volumes of the coarser grained grainstone. Some of the organic wisps have a stylolitic appearance. When 10% HCl is applied to the rock, a strong bituminous odour is emitted. This suggests that the dark grey fraction contains significant bitumen and thus that the primary dark grey laminae held appreciable kerogen. Secondary features affecting the limestone include vugs up 1 cm in diameter, filled or lined with drusy calcite and minor bitumen. Calcite and calcite–bitumen veins up to 5 mm wide are also present.

In Shepody No. 34, the gypsum is light grey and sugary textured and contains solitary and stellate porphyroblasts of selenite. Its marble-like mottling is due to dark grey, irregularly distributed siliciclastic silt and clay. The 4 m of what Crosby and Waugh (1975) called "clay" is in fact reddish brown, very fine-grained sandstone that has incipiently to well-developed micritic calcite nodules and coalesced nodules comprising up to 10% of the rock volume. Descending below the sandstone, the hole intersects 1) 66 cm of silty to fine-grained carbonate grainstone, 2) 13 cm of mottled medium to dark grey, bituminous carbonate mudstone or wackestone containing 1 mm to 1 cm micrite nodules, and 3) 114 cm of algal-laminated limestone. The algal laminae vary from continuous to discontinuous. The rock contains algal oncolites up to 15 mm in diameter and a few thin-walled brachiopod shells, most of which are lined by drusy calcite. Carbonate intraclasts and siliciclastic sand are visible in the algal limestone.

Lockhart Lake: At Lockhart Lake just southwest of New Horton, gypsum is exposed in a small pit about 200 m east-northeast of the northeast corner of the lake. Tan-coloured limestone occurs about 40 m northeast of the pit and 12 m southwest of a prominent waterfilled sinkhole. The limestone contains irregular vugs up to 1.5 cm long, some filled with red mud and others lined with drusy calcite. About 35 m southwest of the pit, a second and similar limestone outcrop occurs in association with a dark grey, lenticular bed of shale up to 5 cm thick. The shale yields a rich miospore assemblage (spore locality 85 on Plate 6). It is unproven whether the steeply dipping limestone and gypsum at Lockhart Lake young toward the northwest or southeast. If the section youngs southeast, the limestone underlies the gypsum as suggested by the bounding rocks of the Mabou Group.

Map unit CLKcc typically consists of conglomerate and sandstone with minor mudstone. In the Sackville Subbasin the unit is well exposed at the south end of the section at Lower Cape. In the Cumberland Subbasin, it crops out near the mouth of Daniels Brook just east of Shepody and along Highway 114 northeast and southwest of the brook. The lower contact of **CLKcc** is not visible at either Lower Cape or Daniels Brook, but the unit is assumed to conformably overlie the sulphates and carbonates of map unit **CLKg**. For example, the mudflats south of Lower Cape may be underlain by sulphates of **CLKg**, and the ponds on the mudflats possibly represent sinkholes. Similarly, the lowlands south of Highway 114 at Shepody Marsh are interpreted to be underlain by recessive sulphates.

Lower Cape: At Lower Cape in the Sackville Subbasin, gypsum of **CLKg** (interpreted to underlie the mudflats south of Lower Cape) is overlain by mainly coarse redbeds of map unit **CLKcc**. The contact between the gypsum and the clastics is not exposed. The redbeds comprise reddish brown, polymictic, pebble to cobble, sandy-matrix conglomerate; reddish brown, medium-grained to granular and pebbly lithic sandstone; minor reddish brown, fine- to medium-grained, parallel- and ripple-laminated sandstone; and minor greyish green to grey siltstone and mudstone. As with the section at Daniels Brook, the coarse conglomerates and sandstones at Lower Cape are concordantly overlain by limestones of map unit **CLKls**, described below.

Daniels Brook: The outcrops along Daniels Brook immediately north of Highway 114 are particularly representative of map unit **CLKcc**. The exposure totals several tens of metres in thickness. It comprises reddish brown, polymictic, pebble to cobble conglomerate; granular to fine-grained lithic sandstone; and rare reddish brown and grey mudstone. The conglomerate beds are up to 1.2 m thick and have subangular to rounded clasts up to 15 cm in diameter of felsic volcanic rocks, dark hard metasiltstone, phyllite, schist, quartzite, schistose granitoid, chloritic mafic volcanic rock, granodiorite, pink leucogranite, purple feldspar porphyry, and vein quartz. The matrix of the conglomerate is calcareous, medium- to coarse-grained lithic sandstone. Conglomerate beds are typically lenticular, have erosive bases, and show cut-and-fill with interstratified sandstone.

The sandstone beds are mainly reddish brown and range from granular to very fine grained. They vary from parallel to lenticular and occur either as thin beds in the thicker conglomerates or as amalgamated intervals up to 1 m thick. The conglomerate–sandstone section shows a general coarsening-upward trend from near Highway 114 to the top of the waterfalls on the brook and a fining-upward trend from the top of the waterfalls to the base of the overlying limestone-bearing unit **CLKls** (Plate 4). In the upper part of map unit **CLKcc**, the sand changes to mostly olive green. Rooted zones appear in the olive sandstones. Beds with parallel parting surfaces contain abundant plant detritus. Some sand beds grade upward into thin beds of grey siltstone and spore-yielding mudstone. The uppermost bed of map unit **CLKcc** in this section is a grey mudstone carrying pedogenic micrite nodules.

Map unit CLKls comprises limestone, limestone-clast conglomerate, limestone breccia, minor conglomerate, sandstone, and mudstone. The unit is exposed and/or intersected at Dorchester, Upper Dorchester and Lower Cape in the Sackville Subbasin; and Hamilton Creek, Chemical Creek, and Daniels Brook in the Cumberland Subbasin.

Dorchester and Upper Dorchester: Limestone is exposed in the earlier-cited small quarry near Upper Dorchester (Plate 4). As well, limestone of the Lime-kiln Brook Formation was intersected in boreholes (Wells 369, 370, and 372 to 376) put down in and near the quarry by Canadian Merrill (St. Peter 2001). Well 370 intersected about 55 m of interbedded limestone, siliciclastics, and siliciclastic-bearing limestone. The limestone in the core occurs in light grey beds forming amalgamated intervals 1 m to 8 m thick. It typically has varied quantities of siliciclastic pebbles and sand, and many beds have micrite nodules. The most carbonate-rich (or siliciclastic-free) limestone beds are characterized by alternating light and dark grey, parallel to wavy, varve-like laminations. The rock was not examined in thin section, but the laminae are presumed to have an algal origin. Small brachiopod shells are rarely noted. Limestone beds are locally separated by laminae or very thin beds of dark grey mudstone.

The limestone intervals commonly show extensive brecciation, both in core from the well and in large boulders in the quarry. The breccia is clast-supported and comprises angular to subrounded clasts up to 10 cm in length of laminated, fine-grained to micritic limestone. The clasts display an interlocking texture as if they were pieces of a jigsaw puzzle showing minimal disturbance. Some clasts display fractures that terminate without projecting fully across the clast. The breccia matrix is arenaceous limestone that infills the 'terminated' fractures in the clasts. This suggests that the brecciation is synsedimentary, possibly as the result of solution collapse. The limestone beds are slightly bituminous and have a strong petroliferous odour when freshly broken. Calcite veins in the limestone and limestone breccia fill many fractures associated with the adjacent Dorchester Fault. Minor barite and celestite also occur in the veins. Tarry bitumen appears in open vugs in the axial zone of a few calcite veins.

The limestone at Upper Dorchester is underlain by and interstratified with grey polymictic conglomerate and medium-grained to pebbly sandstone that define fining-upward intervals with a maximum thickness of 14 m. All the siliciclastic beds have a carbonate matrix. The clasts in the conglomerates are up to 18 cm in length. They comprise cataclastic granite, feldspar porphyritic granite, granite gneiss, quartzite, metasiltstone, chlorite, and sericite schist. Minor intraformational clasts of limestone are also present. The conglomerate is primarily matrix-supported. Sandstone dominates the upper part of fining-upward intervals and tends to be the sole rock type in the upper part of the siliciclastic interval. The clast types in the sandstone beds are similar to those in the conglomerate except that intraformational limestone clasts are more abundant. The matrix of sandstone beds in the lower part of the unit is mostly fine-grained carbonate, whereas that in the upper beds is largely siliciclastic mudstone.

Lower Cape: At the southern end of the section at Lower Cape, map unit **CLKls** conformably succeeds coarse redbeds of map unit **CLKcc**. The rocks of map unit **CLKls** comprise two tongues of grey rocks, mostly limestone, and an intervening unit of coarse redbeds that are indistinguishable from the underlying **CLKcc** redbeds.

The coarse redbeds of **CLKcc** below the lower limestone-bearing tongue are capped by 1.5 m of reddish brown (at the base) and greyish green (at the top), very fine-grained sandstone to subfissile mudstone. The grey beds mark the base of the lower tongue, which at this point in the section has a total thickness of just over 2 m. The grey sandstone and mudstone have minor micrite nodules and tiny plant fragments. The mudstones contain spores (see ***Age,*** below). The plant-bearing clastics are conformably followed by 60 cm of very thin-bedded, brown-weathering, grey, sandy limestone with abundant siliciclastic grains and minor oolites. McCutcheon (1981) records pelmatozoan fragments, ostracods, a high-spired gastropod, and the foram *Paleocrisidia* sp. in the limestone. The limestone is overlain by 20 cm of buff sandy limestone or calcareous sandstone, 65 cm of dark grey, calcareous kerogenous siltstone, and 15 cm of olive grey mudstone. The top of this olive mudstone marks the top of the lower tongue. About 30 m east and along strike of the above section, the lower grey sequence shows an abrupt increase in thickness to 6 m. Commensurate with the thickness increase, the section contains 1) beds of carbonate grainstone with wave-formed ripples, 2) carbonate grainstone or calcareous siliciclastic sandstone with algal stromatolite patches and stromatolite heads, 3) dark grey, organic, subfissile, very fine-grained sandstone to siltstone, and 4) dark grey, organic silty wackestone.

The lower grey sequence is overlain by the intervening redbeds: 15 m of interbedded reddish brown conglomerates, grits, sandstones, and mudstones. This clastic interval is overlain conformably by the upper grey tongue. On the tidal platform, the upper grey unit is about 12 m thick. It comprises 1) grey, non-calcareous sandstone, 2) dark grey, siliciclastic wackestone containing algal patches, 3) carbonate grainstone beds showing cross-bedding, wave-formed ripples or stromatolites (Fig. 34a), and 4) dark greenish grey, oncolitic carbonate mudstone (Fig. 34b; McCutcheon 1981). These grey carbonates are conformably overlain by reddish brown coarse clastics of the Hopewell Cape Formation (Fig. 35). The limestone tongues and intervening redbeds are thus the uppermost exposed strata of the Windsor Group in southeastern New Brunswick.

Hamilton Creek–Chemical Creek: Limestone-clast conglomerate is exposed in a single outcrop on Hamilton Creek, 1.5 km north of Shepody Mountain. The outcrop lies about 60 m east of pre-Late Devonian basement mafic volcanic rocks at Unique Reference Number (URN) 721 (Plate 4). Limestone clasts there are subangular to rounded, up to 15 cm in diameter, and 'float' in a reddish brown, calcareous, muddy siliciclastic matrix. The clasts comprise reddish brown muddy siliciclastic (impure) limestone, grey micritic (clean) limestone, and rare mottled limestone with ovoid to irregular bodies less than 1 mm and up to 10 mm long. The ovoid bodies may be algal oncolites and are largely replaced by black pyrolusite. Pyrolusite also occurs as disseminations and as fracture fills cutting the limestone clasts and, less commonly, the mudstone matrix. Rubbly limestone-clast conglomerate and limestone occur along Chemical Creek, about 1.1 km southwest of the Hamilton Creek exposure. The clasts comprise mainly thin-laminated limestone; the laminae may be algal. Algal-laminated (stromatolitic?) limestone appears in nearby boulders in the streambed. Rare subangular clasts of mafic volcanic rock in the conglomerate look identical to the volcanic basement rock exposed along the creek, a few metres to the north.

Rubbly limestone crops out on a small western tributary of Chemical Creek about 1 km northwest of the intersection of Highway 114 and the road leading to the community of Chemical Road (Plate 4). The limestone is muddy, quite massive, breaks into blocks or slabs, and is notably petroliferous when broken or applied with 10% HCl. It is anomalously fossiliferous and also yielded palynological data (see ***Age***, below). Red polymictic conglomerate north of the limestone has a northerly dip and is interpreted as Hopewell Cape

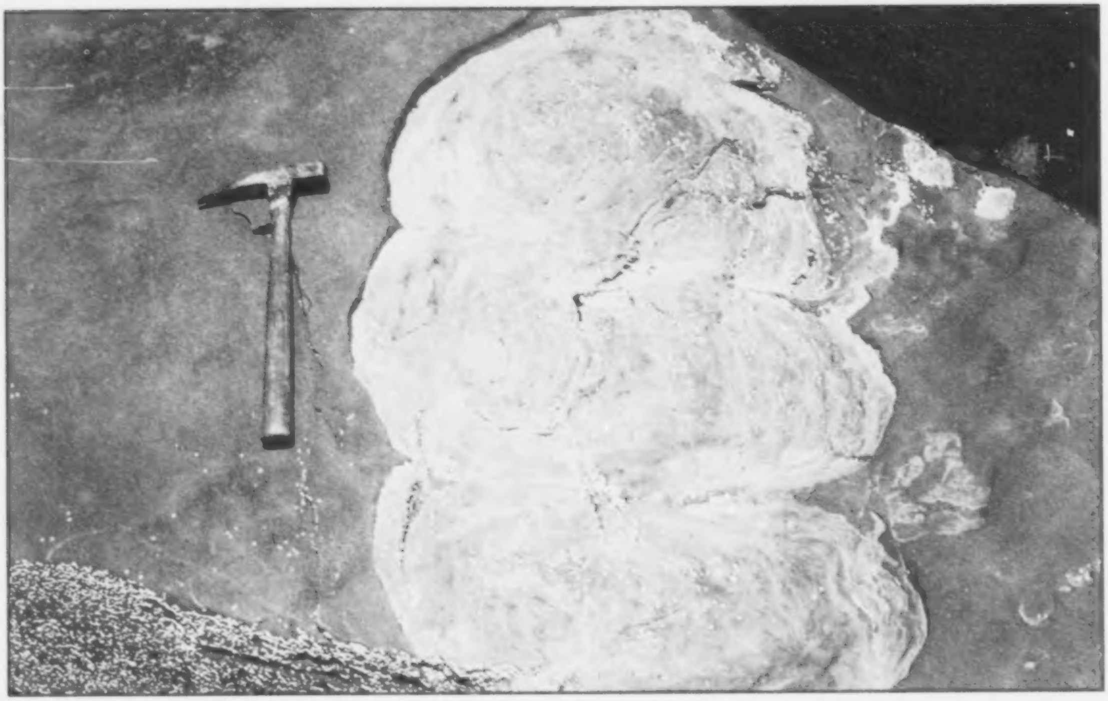


Figure 34a. Laminated algal stromatolite in carbonate grainstone of the Lime-kiln Brook Formation at the southern end of the Hopewell Rocks section, Hopewell Cape (Cape Rocks).

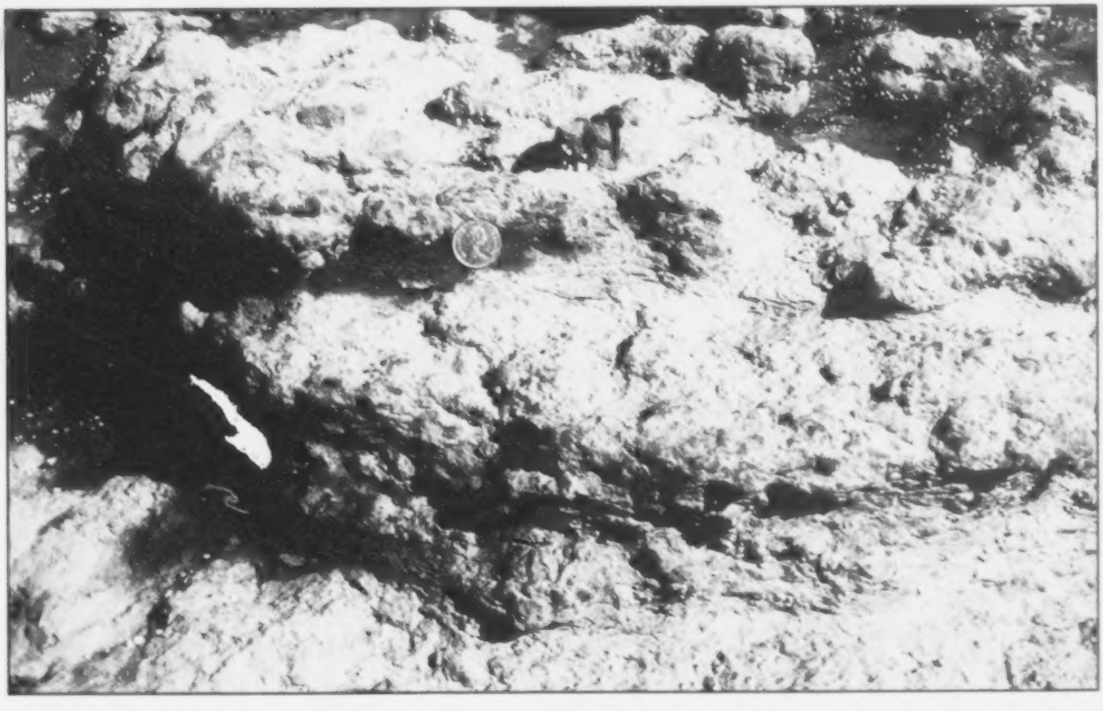


Figure 34b. Lumpy algal oncolitic limestone of the Lime-kiln Brook Formation at the southern end of the Hopewell Rocks section, Hopewell Cape (Cape Rocks). Coin = 2.3 cm.

Formation. The existence of the conglomerate suggests that the limestone at Chemical Creek lies stratigraphically at the top of the Lime-kiln Brook Formation, as it does at Lower Cape and Daniels Brook.

Daniels Brook: A thin interval of limestone from map unit **CLKls** lies above the rocks of map unit **CLKcc** at Daniels Brook. The base of the limestone interval is defined by 4 m of brown-weathering, dark grey, medium- to coarse-grained, very thin-bedded, oolitic and siliciclastic grainstone. That limestone is succeeded by 7 m of brown-weathering, grey, medium-grained, calcareous lithic sandstone. In the middle of the sandstone interval is 30 cm of olive green-weathering shale. The sandstone and shale contain abundant plant detritus and have yielded datable spore assemblages (spore locality AX on Plate 4; see ***Age***, below). The limestone interval is overlain by redbeds of the Hopewell Cape Formation exposed farther upstream above a narrow concealed interval.

Twinned wells near Woodhurst The anomalous sections of possible Lime-kiln Brook Formation in the subsurface of Wells 325 and 330 near Dorchester were discussed above. A third, also lithologically anomalous, section of rocks correlated with the formation appears in the twinned Wells 711 and 716 just northeast of Woodhurst. The well section lies below coarse redbeds of the Hopewell Cape Formation (Mabou Group) and above clean rock salt of the Pugwash Mine Formation. The company litholog for Well 711 is used here as representative of both wells. The section (depth interval 1085–1964 m) consists of about 80% shale and claystone, 11% intraformational breccias, 6% dolostone, 2% rock salt, and 1% anhydrite. The shale and claystone vary from red to grey to rarely black and commonly display vugs formed from leached salt. Intraformational breccias are common in the upper part of the formation and range up to 48 m in apparent thickness. They are red or grey and comprise clasts of claystone and fine- to medium-grained sandstone. Breccias with clasts of anhydrite set in rock salt cement appear in the lower part of the formation. The litholog also reports red to grey dolostone with parallel laminations and traces of salt (1609–1659 m), pink to orange rock salt (1758–1765 m; 1776–1785 m), and dark laminated anhydrite with associated salt (1785–1789 m; 1793–1798 m).

The absence of limestone in the Well 711 section is unusual for the Lime-kiln Brook Formation. However, intervals of laminated dolostone, anhydrite, and rock salt in the otherwise fine-grained clastic formation strongly suggest a series of transgressive marine and regressive terrestrial cycles, features that are characteristic of the formation in the Cumberland Subbasin in Nova Scotia (Ryan and Boehner 1994) and in Cycle 2 of the Windsor Group in general (Giles 1981; von Bitter et al. 2007). The thick intervals of intraformational breccias suggest that significant dissolution of evaporites and consequent collapse of the section took place.

Distribution and Thickness: Exposures of the Lime-kiln Brook Formation are restricted to the Sackville and Cumberland subbasins in the locations summarized below (Fig. 6; Plates 4–6). The subsurface distribution of the formation in these subbasins is not well known, due to the paucity of boreholes.

Sackville Subbasin: Limestone is exposed in the small abandoned quarry (noted above) immediately south of the Harvey–Hopewell Fault near Upper Dorchester. Gypsum crops out on the west shore of Maringouin Peninsula about 1.5 km northwest of Grande Anse (Fig. 3; Plate 4). Limestone and conglomerate are exposed at the south end of the section at Lower Cape, and gypsum appears in a narrow fault wedge northwest of there along the Harvey–Hopewell Fault.

Cumberland Subbasin: Gypsum, shale, and limestone are exposed on the west side of Maringouin Peninsula just northeast of Cape Maringouin (Gussow 1953; Plates 4, 6). An east–west-trending tract of sinkholes cross the peninsula from there to Pecks Cove (Plate 5), suggesting that the area is underlain mostly by gypsum. Several shallow boreholes intersect gypsum of the formation on the northwest side of Chemical Creek along the Harvey–Hopewell Fault. A small outcrop of limestone occurs on a tiny northwest tributary of that creek, northwest of Hopewell Hill (Fig. 6; Plate 4). Conglomerate and limestone are exposed near the mouth of Daniels Brook, and gypsum and limestone were intersected in coreholes on nearby Shepody Marsh (Plate 4).

Before construction of the dam at Harvey Bank, an isolated exposure of gypsum and limestone was visible at low tide on the north bank of Shepody River at Riverside–Albert (Flaherty 1933; Gussow 1953). Gussow (1953) reports a limestone outcrop about 2 km southwest of Riverside–Albert just south of Highway 114. The outcrop is no longer visible but is assumed to have been located southeast of and in fault contact with the Hopewell Cape conglomerate exposure (45°43'50"N; 64°45'16"W) 200 m southeast of the intersection of Highway 114 and the road leading to McFadden Lake. The plotting of map units **CLK$_{ls}$** and **CLK$_g$** on the southeast side of the Harvey–Hopewell Fault in this area is based on the assumption that the limestone of Gussow (1953) was indeed outcrop and his location description is correctly interpreted here. Even farther southwest, a faulted wedge of limestone and gypsum of the Lime-kiln Brook Formation lies just northeast of Lockhart Lake (Plate 6).

The thickness of the Lime-kiln Brook Formation at its type section in Nova Scotia is estimated at 285 m (Ryan and Boehner 1994). About 9 km west of there at Lower Maccan, the formation is 640 m, more than double the thickness of the type section. In New Brunswick in Well 325, the formation has a drill thickness of 422 m (Fig. 32). Outcrops of Hopewell Cape Formation east of the well site indicate a true dip for the section of about 30°SE (Plate 4). Using the dip and a drill thickness of 422 m, the calculated thickness of the formation in Well 325 is 365 m. All other sections in New Brunswick are too incomplete to yield reasonable thickness estimates.

Lower and Upper Boundaries: The lower boundary of the Lime-kiln Brook Formation with the Pugwash Mine Formation is not exposed on surface in the report area. Details on the lower boundary in the subsurface, as revealed in wells in the Sackville Subbasin, appear earlier under ***Pugwash Mine Formation***.

The upper boundary of the Lime-kiln Brook Formation is exposed on the shoreline at Hopewell Cape (Fig. 35). This conformable contact (McCutcheon 1981) is detailed below under ***Hopewell Cape Formation***. The contact between the limestone-bearing unit at Daniels Brook and the overlying redbeds of the Hopewell Cape Formation is also interpreted as conformable. Although the boundary is concealed there by a narrow covered interval, the attitude of bedding on either side of the contact suggests concordance.

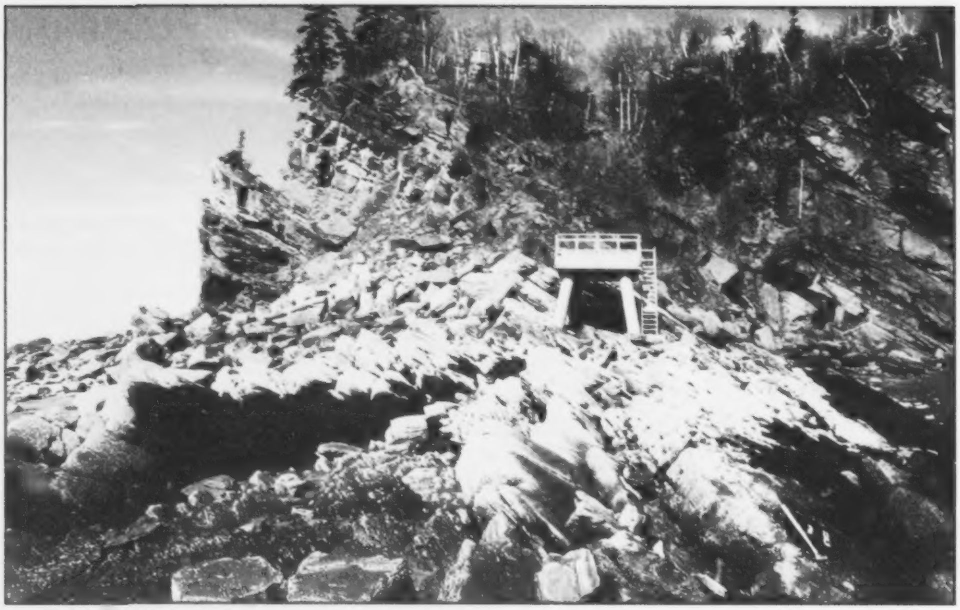


Figure 35. Light grey limestone of the Lime-kiln Brook Formation overlain by red conglomerates and sandstones of the Hopewell Cape Formation at the southern end of Hopewell Cape (Cape Rocks), type section for the Hopewell Cape Formation.

The contact between the Lime-kiln Brook and Hopewell Cape formations is present in Well 325 and in the only Canadian Merrill borehole (Well 371) to cut the formational boundary near Upper Dorchester. These data suggest the boundary may be disconformable in that area, an interpretation based on the depositional environment envisioned for the sulphates of the Lime-kiln Brook versus that postulated for the redbeds of the Hopewell Cape Formation. Sulphates of the Lime-kiln Brook Formation overlie shell-bearing algal limestones at Upper Dorchester, supporting a shallow-marine or possibly sabkha environment of deposition for the sulphates there. In contrast, redbed conglomerates of the Hopewell Cape Formation are interpreted as continental braided stream deposits and probably represent middle to upper alluvial fan lithofacies. The concept of braided stream conglomerates being conformable (depositionally continuous) with sabkha or shallow-marine sulphates contravenes Walther's Law. Consequently, it must be concluded that, where sulphates of the Lime-kiln Brook Formation are overlain by coarse redbeds of the Hopewell Cape Formation, their boundary is likely an erosional disconformity.

Lateral Facies Relationships: The presence of two tongues of algal and stromatolitic marine limestone at Lower Cape interstratified with coarse terrestrial redbed conglomerates demonstrates the facies relationship between marine rocks of the Lime-kiln Brook Formation and their upland terrestrial temporal equivalents. A similar relationship is suggested by the contrast in the Lime-kiln Brook sections between Wells 325 and 330 (Fig. 32).

In Well 330 the Lime-kiln Brook Formation comprises mudrocks and siltstones that contain varied quantities of rock salt. The rock salt exists mostly as dispersed crystals in the mudstones but also as minor interstratal beds. The mudrocks and siltstones of the Lime-kiln Brook Formation show a gradual upward change from mostly grey in the lower part of the formation above the Pugwash salts at 1576 m to mostly red at the uppermost hint of salt at the

Maringouin boundary at 1445 m. The depositional environment of the Lime-kiln Brook Formation in Well 330 is interpreted as a hypersaline marine lagoon (grey beds in the lower part) gradually transgressed by terrestrial muds, perhaps of the distal part of an alluvial plain (redbeds in the upper part). The mudstone-dominated Lime-kiln Brook Formation and gradationally overlying mudstone sequence of the Maringouin Formation in Well 330 apparently change laterally into thick marine sulphates that comprise the entire Lime-kiln Brook Formation in Well 325 (Fig. 32). The following conclusions seem inescapable: 1) the Lime-kiln Brook is underlain by rock salt of the Pugwash Mine Formation in both wells, 2) the thickness of the Lime-kiln Brook Formation in Well 325 is virtually identical to the combined thickness of the Lime-kiln Brook and Maringouin formations in Well 330, and 3) conglomerates of the Hopewell Cape Formation cap both sections.

Depositional Environment: In the Cumberland Subbasin of Nova Scotia, the Lime-kiln Brook Formation contains both marine and terrestrial rocks and accordingly presents a record of marine transgressions and regressions (Ryan and Boehner 1994, p. 17). The stromatolitic and oncolitic carbonate tongues at Lower Cape are interpreted as intertidal to shallow subtidal deposits, whereas the interstratal and subjacent red, fining-upward, repeating cycles of conglomerate, sandstone, and mudrocks are assuredly predominantly terrestrial braided stream deposits. As noted above, the thick sulphate unit that comprises the Lime-kiln Brook Formation in Well 325 is nearly pure anhydrite and gypsum. The absence of any evidence of terrestrial influence (e.g., interbeds of red strata) strongly implies the sulphate is an offshore marine sequence. In Well 330 the grey mudstones and associated rock salt in the lower part of the Lime-kiln Brook Formation point to a hypersaline marine lagoon, whereas the red mudstones with lesser salt in the upper part suggest that the marine environment gradually gave way to an alluvial mudflat.

Near Upper Dorchester, the exposed beds in the limestone quarry and cores from the aforementioned Canadian Merrill drillholes offer evidence of a transgressive sequence. The lowest beds in the core are grey quartzose conglomerates and sandstones containing intraformational limestone clasts and are interpreted as fluvial or, more likely, nearshore beach deposits. Their grey coloration and relatively compositionally mature features, as compared with those of 'typical redbeds', suggest that the terrestrially derived detritus was reworked in a high-energy shoreline environment. The overlying algal and rare shell-bearing limestone is evidently a shallow-marine deposit. The overlying thick interval of gypsum and anhydrite likely represents the product of anomalous salinity (restricted circulation) offshore deposition.

The limestone-clast conglomerates and algal limestones along Hamilton Creek and Chemical Creek indicate a nearshore marine environment. Most of the limestone is brecciated or has limestone clasts in a red siliciclastic (terrestrial?) mudstone matrix, which suggests a postdepositional process, most likely solution collapse. The gypsum outcrops situated farther southwest on Chemical Creek and farther northeast at Lower Cape indicate that more significant gypsum beds probably existed in the Hamilton Creek area but were dissolved or suberoded. The most likely cause of the apparent removal of evaporites and subsequent collapse of interstratal or superjacent carbonates was uplift of the section into the freshwater zone via movement on the Harvey–Hopewell Fault. The limestone-clast conglomerates at Hamilton Creek are analogous to those in the Upperton Formation at Curryville.

Age: Spore assemblages have been recovered from 10 samples of grey mudstone or muddy limestone at Upper Dorchester, Hopewell Cape, Daniels Brook, Chemical Creek, and Lockhart Lake (Table 3). Six of the assemblages indicate a lower middle Visean NS Zone age (Fig. 15) for the formation (Dolby 1996a; Utting 1987). One assemblage at Hopewell Cape (spore locality AW-4 on Plate 4) was assigned a younger age of Visean AT Zone (Fig. 15) by Dolby (1996a). This interpreted age seems too young, considering that it lies stratigraphically below three other samples in the same continuously exposed and unfaulted section, all of which provide ages of NS Zone (Utting 1987).

One thin bed of grey muddy sandstone in limestone from map unit **CLKls** at Upper Dorchester yielded a sparse spore assemblage (spore locality 83 on Plate 4). Dolby (1993) assigned a general Tournaisian age to the assemblage on the basis of its *Rugospora polytycha* and *Retusotriletes* spp., *cf. Anonensis*. The assemblage may in part be reworked material from the adjacent Tournaisian Horton and Sussex groups.

In 1996 Dr. Reginald Moore of Acadia University, Nova Scotia, kindly undertook to examine samples from the anomalously fossiliferous limestone of map unit **CLKls** at Chemical Creek (Table 7). The fauna consists mainly of shell fragments, including echinoid spines and ambulacral plates, ectoprocts (bryozoa), brachiopods, gastropods, bivalves, ostracoda, and possibly worm tubes (Moore 1996). All of these forms occur in Subzone B, indicating the most probable age of the limestone as Windsor biostratigraphic Subzone B (Fig. 15). The absence of foraminifera is suggestive of Subzone A or B, because forams are common in all major late Windsor limestones. The absence of algae and productids and presence of echinoid spines also seem to eliminate the age date of Subzone A. The fossil age assigned to this shelly assemblage by Dr. Moore agrees completely with the palynological age of Visean Zone NS (Fig. 15) assigned to beds from the same outcrop (spore locality 84 on Plate 4) by Dolby (1996a). Gussow (1953) and McCutcheon (1981) list the fossil assemblages recovered from other limestone localities in the Lime-kiln Brook Formation.

Table 7. Fossil assemblage in limestone from the Lime-kiln Brook Formation (map unit **CLKls**) collected at Chemical Creek, Albert County (from Moore 1996). Subzones are after Bell (1929).

Fauna	Species	Windsor Subzones
Bryozoa (Ectoprocta)	Fenestellid fragments– possibly *Septopora*	B and E
	Streblotrypa	B and E
Brachiopoda	*Ovatia lyelli* (nearly entire specimens)	B, C, D, E
	Pugnax sp.	B
	Beecheria sp.	A, B, C, D, E
	Composita windsorensis	B, C, D, E
Bivalvia	*Schizodus fundiensis*	B
Gastropoda	*Aclisina acutula* (nearly entire)	A, B
	Stegocoelia compactoidea	B
	Pseudozygopleura cara?	A, B
Echinoidea	Spines and plates	B, C, D, E
Ostracoda	Several genera	A, B, C, D, E

As a courtesy, Dr. Moore also assessed the likely depositional environment of the Chemical Creek limestone as indicated by its faunal material. The micritic matrix suggests low energy. Autochthonous productids (supported by spines) would require low-energy conditions. Yet the fragmental nature of most shells suggests relatively high-energy conditions in the source area, above wave base. The abundance of echinoid debris points to nearly normal salinity. *Schizodus* is a burrowing clam and would have required a fairly soft substrate. Foraminifera are common in shallow water, and their absence suggests a relatively deep-water environment. Thus, it appears that much of the shell material was carried from the nearshore area into deeper water, possibly through storm action, before settling out of suspension.

In summary, the Lime-kiln Formation falls within the NS miospore zone of Utting (1987) and macrofaunal Subzone B of Bell (1929), thus indicating a middle Visean age.

Relationship to Previous Stratigraphy: Norman (1941a) placed the limestone along the Harvey–Hopewell Fault at Upper Dorchester in the Albert Formation. He left the gypsum and limestone along the fault from Lower Cape to Riverside–Albert, the gypsum at Shepody Marsh, and the gypsum on Maringouin Peninsula as undivided Windsor Series. Limestone tongues at Lower Cape and Daniels Brook were allocated to the Hopewell Group (Mabou Group of current usage: see below) by Norman (1941a). Flaherty and Norman (1941) included the gypsum and limestone at Lockhart Lake in the undivided Windsor Series. Gussow (1953) assigned the rocks placed herein in the Lime-kiln Brook Formation in the Windsor Group as a lower map unit (**Mwg**) of gypsum (locally containing conglomerate near its base) and an upper map unit (**Mwl**) of limestone. He did not distinguish sulphates in the Upperton Formation from younger sulphates of the Lime-kiln Brook Formation.

McLeod and Ruitenberg (1978) mapped the limestone at Upper Dorchester as map unit 4 of the undivided Windsor Group. McLeod (1980) mapped the gypsum north of Lower Cape as map unit 7b and the limestone at Hamilton Creek and Chemical Creek as map unit 7c of the Windsor Group. In his 1981 thesis, McCutcheon assigned the limestone and gypsum along the Harvey–Hopewell Fault from Lower Cape to Chemical Creek and the beds at Shepody Marsh as undivided Macumber Formation (limestone) and Upperton Formation (gypsum). However, the limestone beds at Chemical Creek and in the Shepody Marsh coreholes are lithologically dissimilar to the laminated limestone of the Macumber Formation. He informally referred to the limestone tongues at Lower Cape and Daniels Brook as Demoiselle Creek beds. In the same thesis, McCutcheon allocated the conglomerates and sandstones underlying his Demoiselle Creek beds to an undivided unit of the Windsor Group.

MABOU GROUP

The name 'Mabou Group' was introduced by Belt (1964, 1965) to describe non-marine red and grey sandstone and shale along the southwest Mabou River, Cape Breton Island, Nova Scotia. He suggested using the Mabou Group throughout Nova Scotia and New Brunswick, essentially replacing the Canso Group in Nova Scotia and the Hopewell Group in New Brunswick. Although his idea gained little early acceptance, Mabou Group was eventually adopted in Nova Scotia (Ryan et al. 1991; Ryan and Boehner 1994). With the intention of simplifying group nomenclature for Carboniferous strata across the region, the present authors propose to adopt the term 'Mabou Group' in New Brunswick for strata formerly assigned to Zone 1 of the Petitcodiac Series of Wright (1922), the Demoiselle Formation of Norman (1932), and the Hopewell Group of Norman (1941a; Fig. 9). Although the Hopewell

Group is widely referred to in the literature, its primary use has been for undivided units of red conglomerate, sandstone, and mudstones (e.g., Norman 1941a; Stewart 1941b, 1941c; Evans and Alcock 1945; Alcock and MacKenzie 1946; Hamilton 1961b; St. Peter 1993).

The Mabou Group is used herein to describe a dominantly redbed succession of Early Carboniferous (middle Visean to early Namurian) age that overlies the Windsor Group and is disconformably to unconformably overlain by the Late Carboniferous Cumberland and/or Pictou groups (Fig. 8). The Mabou Group in New Brunswick consists of a proximal, coarse alluvial fan facies given the name 'Hopewell Cape Formation' (new) and the basinward equivalent rocks of the Maringouin, Shepody, and Enragé formations. Both the proximal, basin-margin facies represented by the Hopewell Cape Formation and the lowermost, distal, basin-axis facies represented by the Maringouin Formation gradationally overlie marine rocks of the Windsor Group and are therefore in large part temporally equivalent (Fig. 36).

The thickness of the Mabou Group in New Brunswick ranges from less than 50 m in areas where the condensed Hopewell Cape Formation nonconformably overlies Neoproterozoic basement rocks of the Caledonia and Westmorland uplifts (Fig. 6) to a maximum of about 2000 m in the axial part of the Cumberland Subbasin in Nova Scotia (Ryan and Boehner 1994). The thickness of the Mabou Group on the south limb of the Maringouin Anticline (Fig. 6, inset) in the Cumberland Subbasin in New Brunswick is about 950 m.

In the axial part of the Cumberland Subbasin, the Mabou Group consists of a coarsening-upward redbed sequence that comprises, in ascending order, the Maringouin, Shepody, and

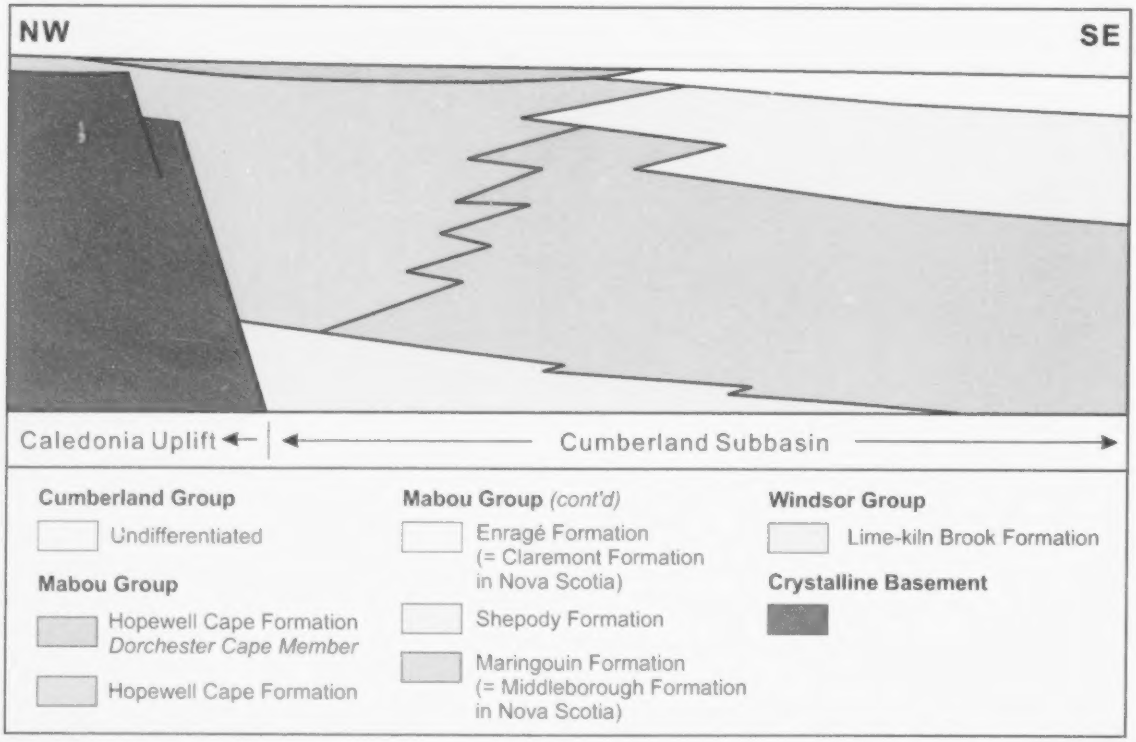

NW
SE
Caledonia Uplift
Cumberland Subbasin
Cumberland Group
Undifferentiated
Mabou Group
Hopewell Cape Formation
Dorchester Cape Member
Hopewell Cape Formation
Mabou Group (cont'd)
Enragé Formation
(= Claremont Formation in Nova Scotia)
Shepody Formation
Maringouin Formation
(= Middleborough Formation in Nova Scotia)
Windsor Group
Lime-kiln Brook Formation
Crystalline Basement

Figure 36. Conceptual cross-section of proximal–distal relationships among formations of the Mabou Group in southeastern New Brunswick and the adjacent Cumberland Subbasin in Nova Scotia.

Enragé formations (Fig. 9). On the northwestern margin of the Cumberland Subbasin, the Mabou Group is represented by coarse conglomerates of the Hopewell Cape Formation. To the north in the Sackville Subbasin, the group comprises a basin-edge proximal unit, the Hopewell Cape Formation (including the Dorchester Cape Member in its upper part), and a basinward or distal unit, the Maringouin Formation. In the Sackville Subbasin southeast of Sackville (Plate 5), gravity data (Gussow 1953; Hassan 2000) suggest the existence of rock salt in the shallow subsurface near the head of Cumberland Basin. This implies that cap rocks of the Mabou Group are likely exhumed there. No outcrops to substantiate the interpretation are known, and for this reason the Mabou Group is simply mapped as undivided in that area.

In the eastern Moncton Subbasin and on the Westmorland Uplift, rocks of the Mabou Group include exposed conglomerate-dominated strata of the Hopewell Cape Formation and underlying buried redbeds of an unnamed unit. A condensed, very thin section of Hopewell Cape rocks lies unconformably on the south flank of the Caledonia Uplift. Coarse redbeds of the Mabou Group on the southeastern part of the New Brunswick Platform lie unconformably above the Windsor Group and unconformably below the Cumberland or Pictou groups; these redbeds are assigned to the Shin Formation. The Shin Formation is not exposed in the report area and will not be discussed further.

The major lithological subdivisions of the Mabou Group as defined herein are comparable with those given for the Hopewell Group by Norman (1941a) and more rigorously by Gussow (1953). However, the definition in the current report differs with respect to the location of the formational contacts, particularly the Enragé Formation, and Gussow's interpretation of the nature of the Enragé–Boss Point contact (Mabou–Cumberland boundary). The definition also differs from Ryan et al. (1991) in their description of the Mabou Group in the Cumberland Subbasin in Nova Scotia with respect to the overlying Enragé Formation and the lithologically and time-equivalent Claremont Formation. The present authors designate these strata as Mabou Group, whereas Ryan et al. (1991) assign the Claremont rocks to the overlying Cumberland Group. An historical basis exists for both assignments. The Claremont Formation was traditionally grouped with the Boss Point Formation in the Riversdale Group of Bell (1944, 1958); the Enragé Formation was originally assigned to the Hopewell Group by Norman (1941a). Norman likely included the Enragé Formation in the Hopewell Group due to broad lithological similarities between the Enragé Formation and parts of his (1941a) undivided Hopewell Group at Lower Cape (Hopewell Cape Formation of this report). Bell (1914) initially included Claremont strata in the Boss Point Formation but later divided it into the Claremont and Boss Point formations of the Riversdale Group (Bell 1944). Ryan et al. (1991) and Ryan and Boehner (1994) then abandoned the Riversdale Group, and its constituent formations were reassigned to the Cumberland Group.

The authors strongly recommend herein that the Enragé Formation be retained within, and the Claremont Formation be reassigned to, the Mabou Group. As discussed later (under ***Enragé Formation*** and ***Cumberland Group***), supporting evidence includes the lithological similarities of the Enragé and Hopewell Cape formations, the significant lithological differences between the Boss Point Formation and the revised Enragé Formation, and the post-Enragé–pre-Boss Point gap in the macrofloral and palynological record at the early Namurian level (Bell 1944; Dolby 1996a, 1996b, 1997a; Utting and Giles 1998). The contact between the Mabou and Cumberland groups is a significant stratigraphic break that, in all probability, is coincident with the Early Carboniferous (Mississippian)–Late Carboniferous (Pennsylvanian) boundary. Although the hiatus was recognized by Gussow (1953) and Carr (1968), they positioned this break at the base of their undated Enragé Formation within their Hopewell Group.

As a matter of choice, the more distal or basinal units — the Maringouin, Shepody and Enragé formations — are described here before the laterally adjacent basin margin and upland strata of the Hopewell Cape Formation.

Maringouin Formation

Authors: Norman (1941a); revised by Gussow (1953).

Type Section: Williams et al. (1985) recommends the type section as the coastal exposures on the southwest side of Maringouin Peninsula between 2.8 km and 1.5 km north of Cape Maringouin in Westmorland County (NTS 21 H/10; Plate 6). The locality is the most complete and well-exposed section and is designated herein as the type section (Fig. 37, 38).

Reference Section: A less complete but more accessible section is found on the north side of Pecks Point on the eastern shore of Maringouin Peninsula (NTS 21 H/16).

Definition and Description: Norman (1941a) introduced the name 'Maringouin Formation' to describe red shale and sandstone that conformably overlie the Windsor Group on Maringouin Peninsula. Gussow (1953) subsequently described the lithological character and boundaries of the formation in greater detail.

The Maringouin is the lowest formation of the Mabou Group in the axial part of the Sackville and Cumberland subbasins. It comprises brick red to reddish brown, commonly massive mudstone and siltstone (Fig. 39a, 39b); red, calcareous, very fine-grained to fine-grained, ripple- and climbing ripple-laminated sandstone (Fig. 39b); and minor, small-scale trough cross- and parallel-bedded sandstone. Mudcracks are common in mudstone and siltstone beds. The sandstones are almost entirely red with very rare, grey sandstone beds near the base in the type section.

Van de Poll (1973a) notes that the Maringouin Formation at Pecks Point coarsens upward. Mapping by the present authors at this locality and other well-exposed sections such as stream sections west of Lowell and Midway (Plate 6) support his observation. In outcrop, sandstone-dominated intervals are commonly less than 3 m thick in the lower part of the formation and become more abundant and thicker (up to 6 m) upsection. Lateral pinching of the sand bodies forming wedge-shaped geometries is characteristic of the formation. Carbonized root casts appear in several places, indicating soil development in some of the mudstones. Curved joints in siltstone and mudstone beds on the south side of Shepody River at Harvey Bank are interpreted as evidence of vertisol development. Small blocky or lumpy geometries a few millimeters in diameter are locally common and are interpreted as soil peds. Reduction spheroids and reduction along bedding planes and foreset laminae are also common. Selected siltstone and mudstone beds contain clusters of small, roughly spherical cavities 3 mm to 10 mm in diameter, possibly weathered-out carbonate or iron-carbonate nodules.

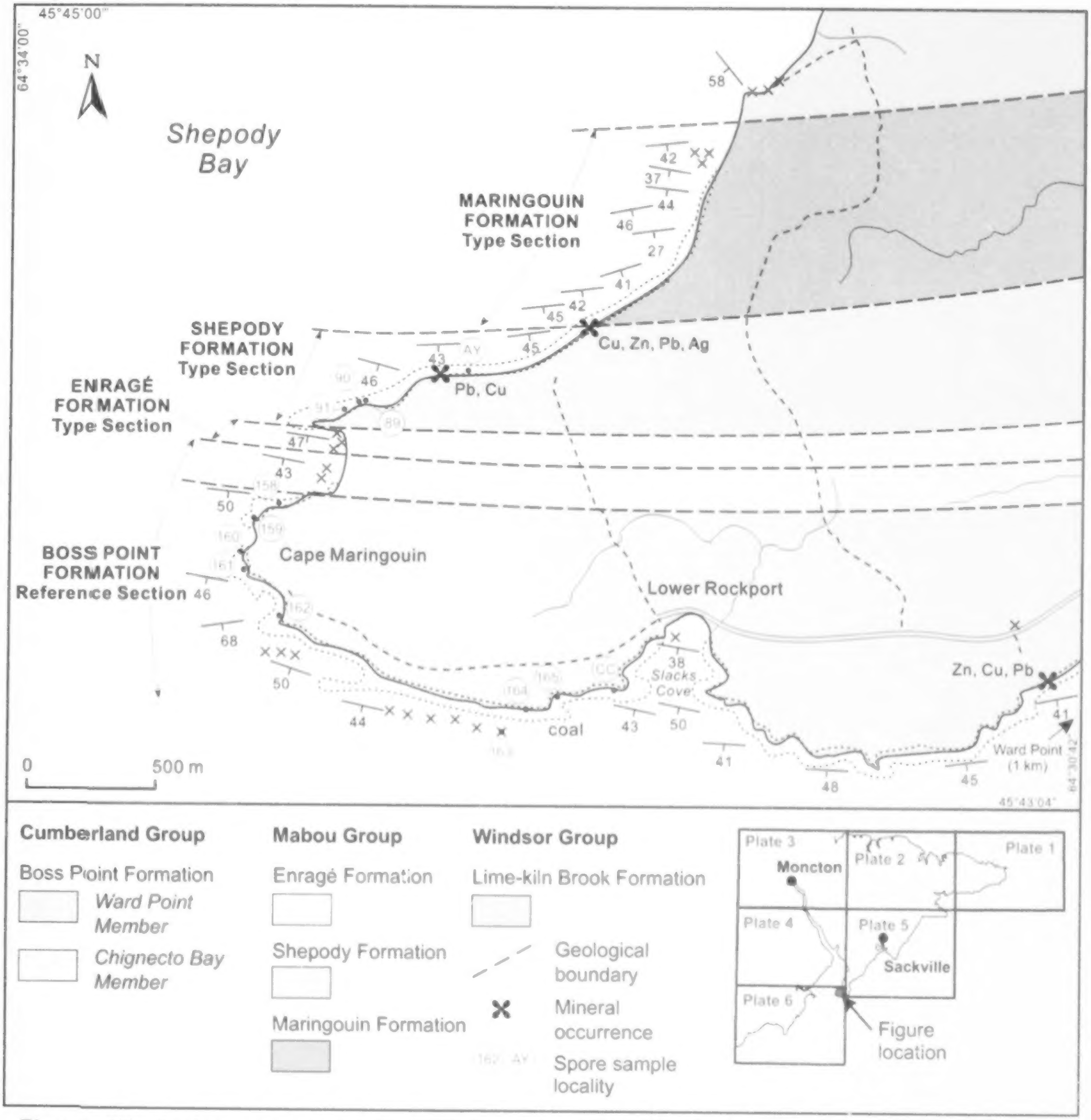

45°45'00"
64°34'00"
N
Shepody Bay
MARINGOUIN FORMATION Type Section
SHEPODY FORMATION Type Section
ENRAGÉ FORMATION Type Section
BOSS POINT FORMATION Reference Section
Cape Maringouin
Lower Rockport
Slacks Cove
Cu, Zn, Pb, Ag
Pb, Cu
Zn, Cu, Pb
coal
Ward Point (1 km)
0
500 m
64°30'42"
45°43'04"
58
42
37
44
46
27
41
42
45
45
43
46
47
43
50
46
68
50
44
43
50
38
41
48
45
41
AY
90
91
89
158
159
160
161
162
163
164
165
CC
Cumberland Group
Boss Point Formation
Ward Point Member
Chignecto Bay Member
Mabou Group
Enragé Formation
Shepody Formation
Maringouin Formation
Windsor Group
Lime-kiln Brook Formation
Geological boundary
Mineral occurrence
Spore sample locality
Plate 1
Plate 2
Plate 3
Plate 4
Plate 5
Plate 6
Moncton
Sackville
Figure location

Figure 37. Geology map showing the type sections for the Maringouin, Shepody, and Enragé formations and reference section for the Boss Point Formation at Cape Maringouin.

Well 146 near Colpitts Settlement and Well 319 near Turtle Creek (Fig. 13) occur in the extreme western part of the report area. They intersected a coarsening-upward sequence of redbeds that overlie Windsor rocks (limestone in Well 146 and gypsum or anhydrite in Well 319), and in both wells are overlain by the Boss Point Formation. The coarsening-upward sections at both wells can be subdivided into three parts: a lower red mudstone and siltstone-dominated section, a medial sandstone-dominated section, and an upper conglomeratic section. The three-part stratigraphy is comparable with the upward coarsening Maringouin, Shepody, and Enragé stratigraphy in the Cumberland Subbasin. The well sections differ somewhat from the Cumberland surface sections. For example, sandstones in the medial

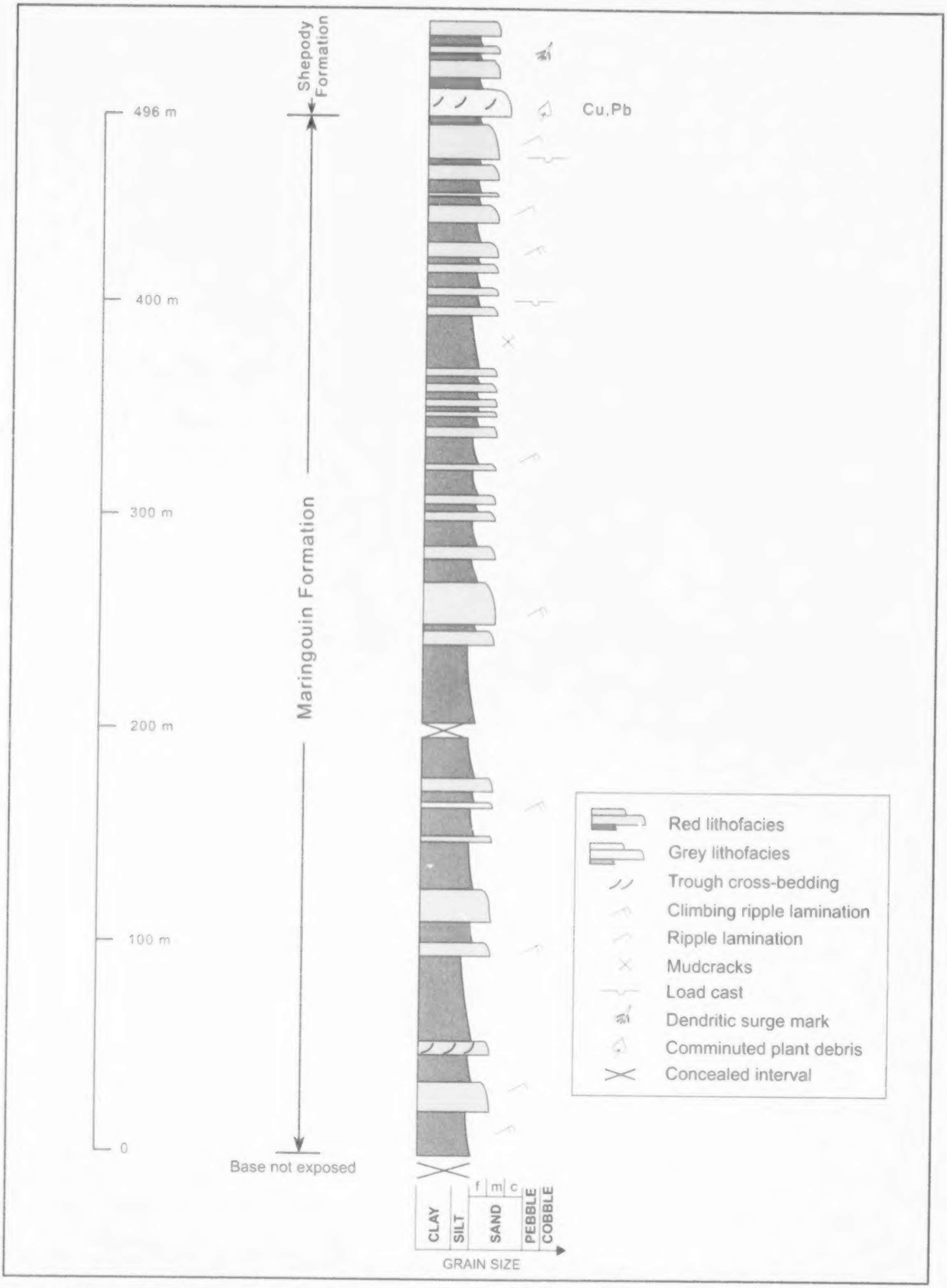

Shepody Formation
496 m
400 m
300 m
200 m
100 m
0
Maringouin Formation
Base not exposed
Cu,Pb
f
m
c
CLAY
SILT
SAND
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Trough cross-bedding
Climbing ripple lamination
Ripple lamination
Mudcracks
Load cast
Dendritic surge mark
Comminuted plant debris
Concealed interval

Figure 38. Generalized stratigraphy of the type section for the Maringouin Formation at Cape Maringouin.

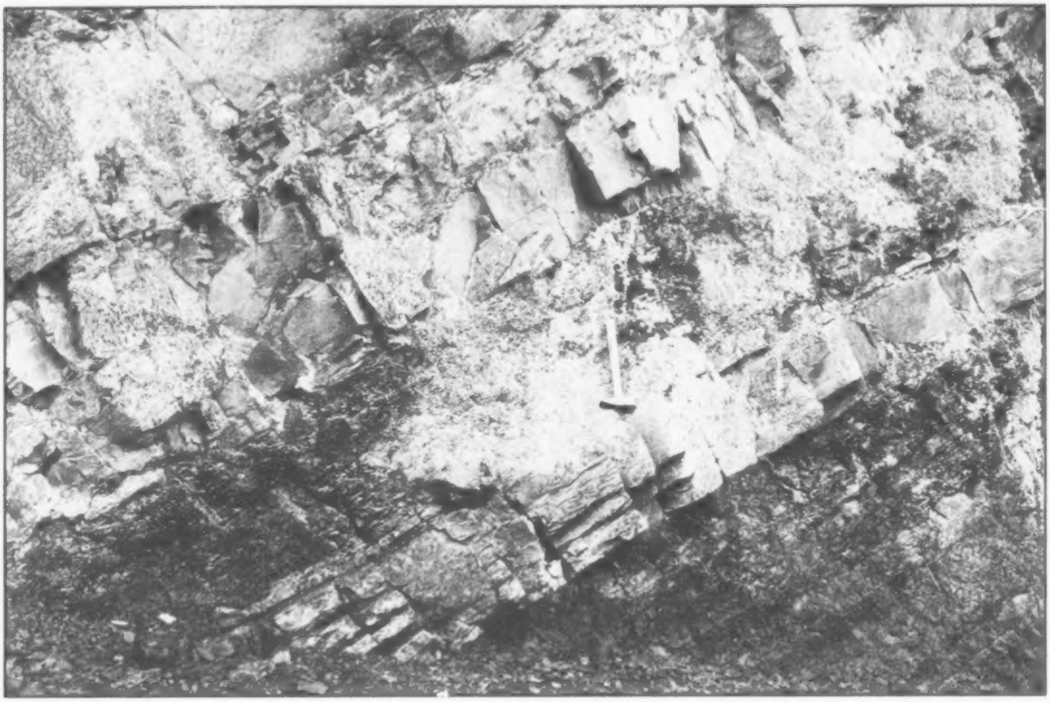


Figure 39a. Red, fine-grained sandstone–siltstone intervals in upper part of the Maringouin Formation between Pecks Cove and Pecks Point, east side of Maringouin Peninsula. Note green coloration due to reduction along fractures.

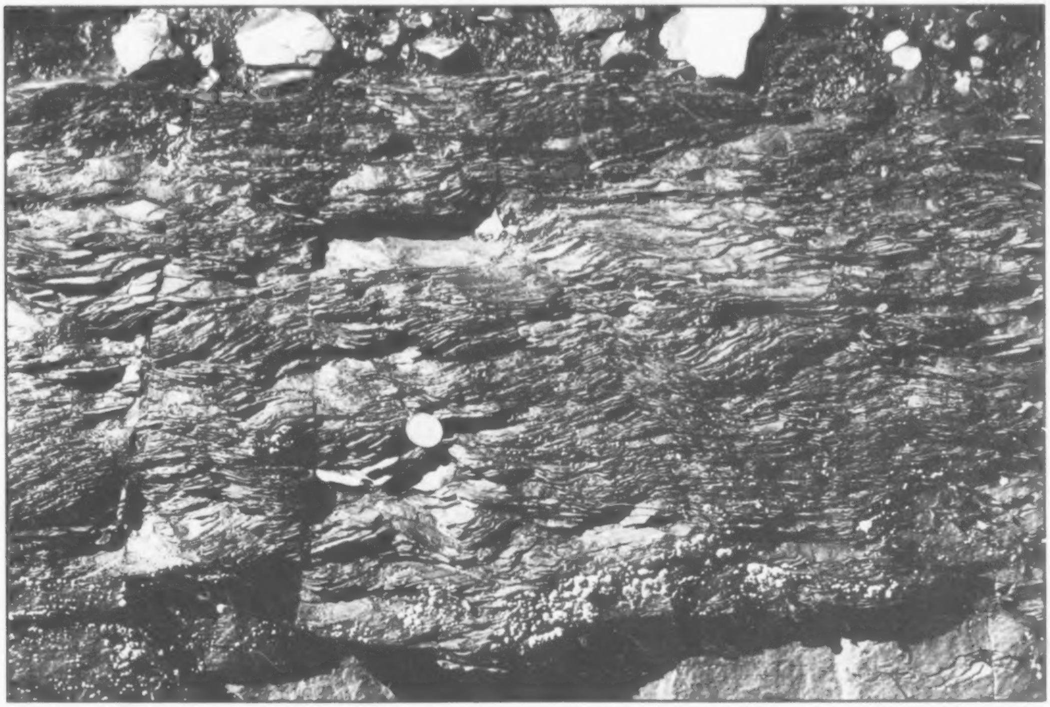


Figure 39b. Climbing-ripple laminations in red siltstone of the Maringouin Formation at Pecks Point, east side of Maringouin Peninsula. Coin diameter = 2.6 cm.

interval in the wells are typically red and only rarely grey, differing from sandstones of the exposed Shepody Formation, which are more commonly grey and plant-bearing. For this reason it is suggested that the well sections should simply be subdivided into two parts: a lower mudstone–siltstone–sandstone sequence and an upper conglomeratic sequence. The well sections are thereby analogous to the Maringouin Formation and the overlying Hopewell Cape Formation exposed at and south of Dorchester Cape on the east side of Shepody Bay (see Gussow 1953, his Fig. 5).

The lithologs for Wells 146 and 319 indicate that the lower unit of mudstone, siltstone, and sandstone comprises a series of stacked, fining-upward, sandstone–siltstone–mudstone sequences from 1 m to 30 m in thickness. The thickness and frequency of the sand part of the cycles become greater upward in the section. The drill thickness of the formation in Well 319 is 215 m and in Well 146 is 450 m, indicating a significant increase in thickness toward the north and west. This observation is supported by seismic reflection profiles in the area, which show that the Mabou Group dips gently toward the north and is greater than 1 km thick north of Well 146 (St. Peter 1992).

Distribution and Thickness: The formation as mapped by previous workers (Flaherty and Norman 1941; Norman 1941a; Gussow 1953) is restricted to the Cumberland Subbasin. In the report area, this would consist solely of exposures on Maringouin Peninsula and in the area between Rocher Bay and Shepody Marsh. In the current report, however, the Maringouin Formation also includes the red sandstones and mudrocks that lie concordantly below conglomerates of the Hopewell Cape Formation south of Dorchester Cape in the Sackville Subbasin. In addition, the coarsening-upward section of redbeds above Windsor rocks in wells in the northwest part of Plate 4 (and on Fig. 9) are correlated herein with the Maringouin Formation.

A minimum measured thickness of the type section on the south limb of the Maringouin Anticline (Plates 5, 6) is 496 m. A total thickness of about 700 m is possible; concealed measures separate the lowest exposed beds of the type section from exposures of the underlying Windsor Group. The formation is estimated to be in the order of 1200 m to 1300 m thick on the limb of a southeast-dipping monocline near the mouth of Shepody River (Plate 6). The section correlated with the Maringouin Formation in Well 146 (Fig. 13) is between 400 m to 450 m thick. South and east of that well, the formation thins to a zero edge in the subsurface, as evidenced by other well records from the area. Additionally, the formation is not exposed (does not exist) south of the outcrop edge of the Boss Point Formation.

Lower and Upper Boundaries: Norman (1941a) and others (Bell 1944; Gussow 1953) considered the contact with the underlying Windsor Group (Lime-kiln Brook Formation) to be conformable, although it is not exposed in the report area. The Maringouin Formation is equivalent to the Middleborough Formation in the Joggins section of Nova Scotia, which conformably overlies the Lime-kiln Brook Formation of the Windsor Group (Ryan and Boehner 1994). The contact with the overlying Shepody Formation is gradational, as exhibited by the Maringouin Formation becoming more sand-dominated and greyer toward the top. The contact is arbitrarily positioned at the first major grey, trough cross-bedded sand body, commonly containing plant remains. The basal Shepody contact is exposed at several localities, including at the type section near Cape Maringouin, at Pecks Point (Fig. 40), along

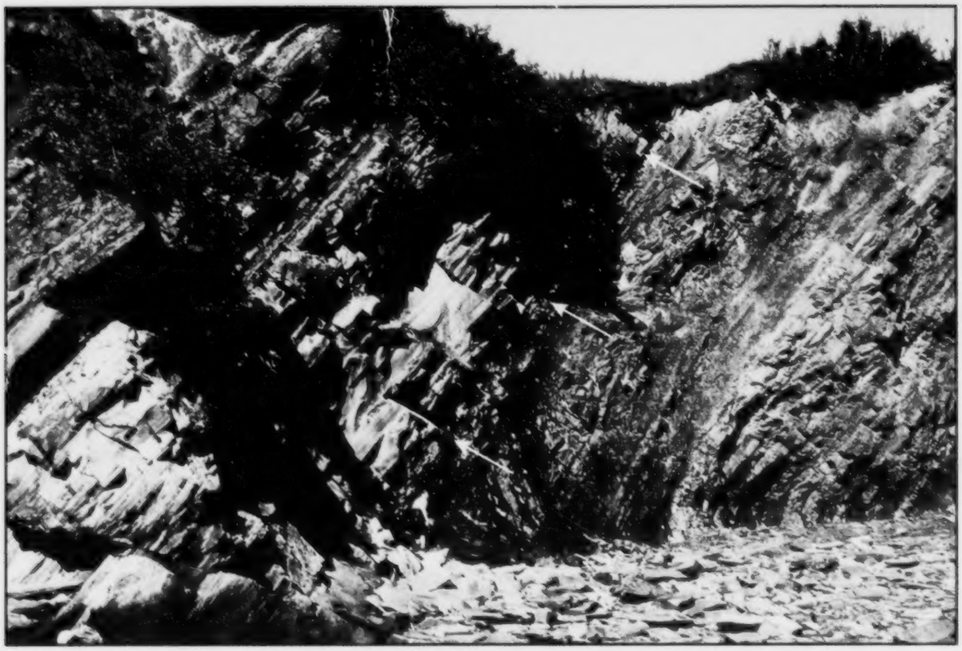


Figure 40. Gradational contact (arrows) between the Maringouin Formation (right) and the overlying Shepody Formation (left) at Pecks Point on Maringouin Peninsula.

Shepody Bay south of Johnson Mills, and at Inner Head near Cape Enrage. Neither the lower boundary with the Windsor Group nor the upper contact with the Shepody Formation has been modified from its original definition.

In the Sackville and eastern Moncton subbasins, the red mudstones and sandstones that characterize the Maringouin Formation are concordantly and gradationally succeeded by red grits and conglomerates of the Hopewell Cape Formation. The typical grey plant-bearing sandstones of the Shepody Formation are not exposed and have not been intersected in wells in this area. The Mabou Group in these basins, where it lies on the Windsor, gradually coarsens upward and accordingly has a sand-dominated medial part, such as occurs south of Dorchester Cape (Gussow 1953) and in the subsurface north of Parkindale. However, the sandy interval is predominantly red and is not sufficiently different to distinguish it from the Maringouin Formation. The contact of the Maringouin with the Hopewell Cape Formation is exposed at the south end of the Dorchester Cape section (Fig. 41) and was intersected 6 km north of there in Well 330 (Fig. 32). Similarly, the lithologs of Wells 146 and 319 in the western extremity of the report area (Fig. 13) strongly suggest a gradational boundary with the overlying Hopewell Cape Formation. This conclusion is supported by concordance between seismic reflectors within the Mabou Group in profiles that cross those wells.

Lateral Facies Relationships: Bell (1927, 1944) and Gussow (1953) considered the Maringouin Formation to be conformable and in part diachronous with the late Windsor Group. Their conclusion is supported by litholog records from Wells 325 and 330. In both wells the Lime-kiln Brook Formation is underlain by the Pugwash Mine Formation. In Well 330 the Lime-kiln Brook beds are succeeded by the Maringouin redbeds, and the two formations have an aggregate true thickness of about 330 m (Fig. 32). However, in Well 325 to the north, the Maringouin Formation is absent, and the Lime-kiln Brook Formation is about 330 m thick

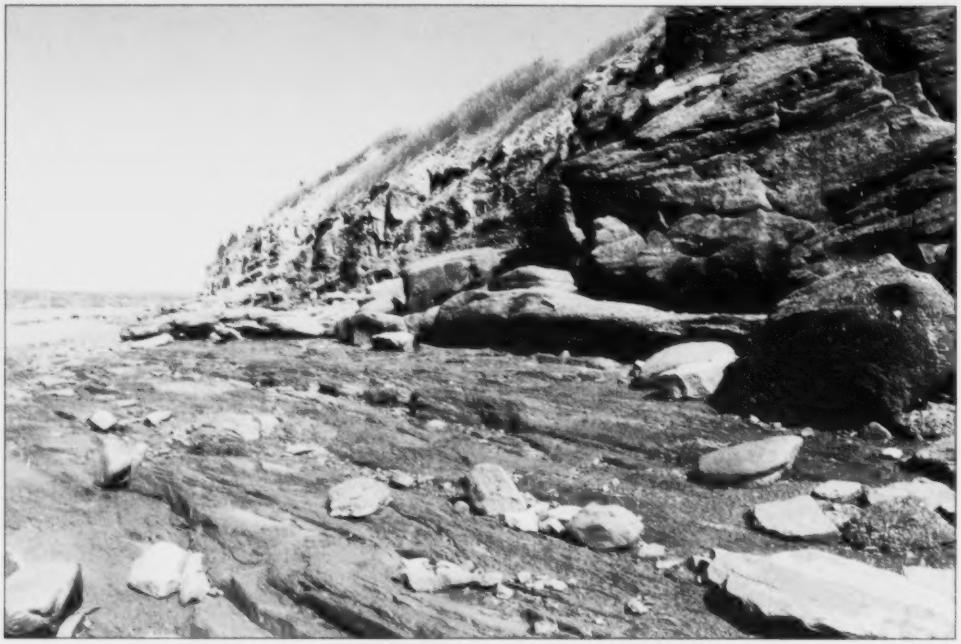


Figure 41. Contact between the Maringouin Formation (foreground) and the overlying Hopewell Cape Formation at Dorchester Cape.

(more than twice its thickness in Well 330), occupying the entire interval between the Pugwash Mine evaporites and Hopewell Cape conglomerates. The relationship implies a lateral intertonguing of the Maringouin and Lime-kiln Brook formations. It further hints at the Maringouin Formation being on the upland side of a Windsor depocentre to the north. The distribution of lithofacies in the Pugwash Mine Formation, as revealed in the two wells, also suggests a northern Windsor depocentre (see ***Pugwash Mine Formation***, earlier).

Gussow (1953) cites the Maringouin as being partly equivalent to the lower part of the Hopewell Cape conglomerate, and the present authors support his contention. The Hopewell Cape Formation concordantly overlies the uppermost tongue of limestone of the Lime-kiln Brook Formation at Hopewell Cape. Surface exposures on Maringouin Peninsula and in the Cumberland Subbasin of Nova Scotia (Ryan and Boehner 1994) indicate that the Maringouin Formation is concordant with the Lime-kiln Brook Formation. The Maringouin Formation is therefore interpreted as the basal distal equivalent of the proximal Hopewell Cape Formation in New Brunswick (Fig. 36).

Depositional Environment: The predominance of mud over sand and the occurrence of multiple-stacked, fining-upward sandstone, siltstone, and mudstones cycles that are a few metres to decimetres in thickness both suggest deposition by fairly small rivers. The upward increase in thickness of the cycles implies the rivers gradually became larger and more competent. The occurrence of climbing ripple laminations in some of the sandstone beds implies very rapid deposition, perhaps by unchannelized sheet floods. Carbonate nodules, mudcracks, and locally rooted zones in the mudrocks indicate periods of considerable exposure and soil development in an alluvial plain environment. A distal alluvial plain environment is proposed herein for the Maringouin Formation, in keeping with its stratigraphic position lateral to the Hopewell Cape Formation. The proximity and lateral relationship with the Lime-kiln Brook Formation presumably led van de Poll (1973a) to envision a playa–coastal mudflat environment for the Maringouin Formation.

Age: The nearly exclusively red coloration of Maringouin mudrocks seriously hampers dating the formation with miospores. However, a grey mudstone bed within a few metres of the top of the formation at spore locality 86 on the east side of Rocher Bay (Plate 6) at Inner Head yields a possibly latest Visean age (Dolby 1997a). A maximum age for the Maringouin Formation is established by the presence of middle Visean spores at the base of the laterally equivalent Hopewell Cape Formation at Hopewell Cape (Utting 1987). Latest Visean to early Namurian spore assemblages from the overlying Shepody Formation serve to bracket the age.

Relationship to Previous Stratigraphy: In this report, the definition of the Maringouin Formation in the Cumberland Subbasin follows that of Norman (1941a) and Gussow (1953). It is equivalent to the lowermost 295 m of Logan's (1845) Division VIII in the Joggins section, which is currently assigned to the Middleborough Formation in Nova Scotia (Ryan and Boehner 1994). In the Sackville Subbasin, the definition of the Maringouin Formation is expanded to incorporate the red sandstones and mudstones that Gussow (1953, his Fig. 5) assigned to the Shepody Formation south of Dorchester Cape. In the Moncton Subbasin, the subsurface redbeds that concordantly underlie the Hopewell Cape Formation north and west of Parkindale are correlated with the Maringouin Formation.

Shepody Formation

Author: Norman (1941a).

Type Section: Although neither Norman (1941a) nor Gussow (1953) defined a type section for the Shepody Formation, Williams et al. (1985) used Gussow's map to recommend a type section between 0.8 km and 1.5 km north of Cape Maringouin (Fig. 37, 42) on the east side of Shepody Bay, Westmorland County (NTS 21H/10; Plate 6). The present authors herein place the boundary between the Shepody and Enragé formations somewhat higher in the section than did Gussow and thus are more in accordance with Norman (1941a). Included in the Shepody Formation are the competent trough cross-bedded sandstones that form a small headland on the north side of a tiny cove that is partly carved from the more recessive and friable Enragé strata (Fig. 37). Consequently, the type section on Maringouin Peninsula is revised herein to include strata between 0.7 km and 1.5 km north of Cape Maringouin, as shown on Map 647A of Norman (1941a).

Reference Section: Ryan and Boehner (1994) designate the Joggins shoreline east and north of Downing Cove, toward Mill Cove in Cumberland County, Nova Scotia (NTS 21H/16), as a reference section for the Shepody Formation.

Definition and Description: The Shepody Formation comprises grey, reddish brown, red, and pink lithic and quartzose arenite, intraformational conglomerate, siltstone, and mudstone. The definition of the formation used herein appears to be identical to Norman's (1941a) intended definition. Although he did not give a comprehensive description of the contacts, his map of Cape Maringouin (Map 647A) clearly places the contacts in the same position as

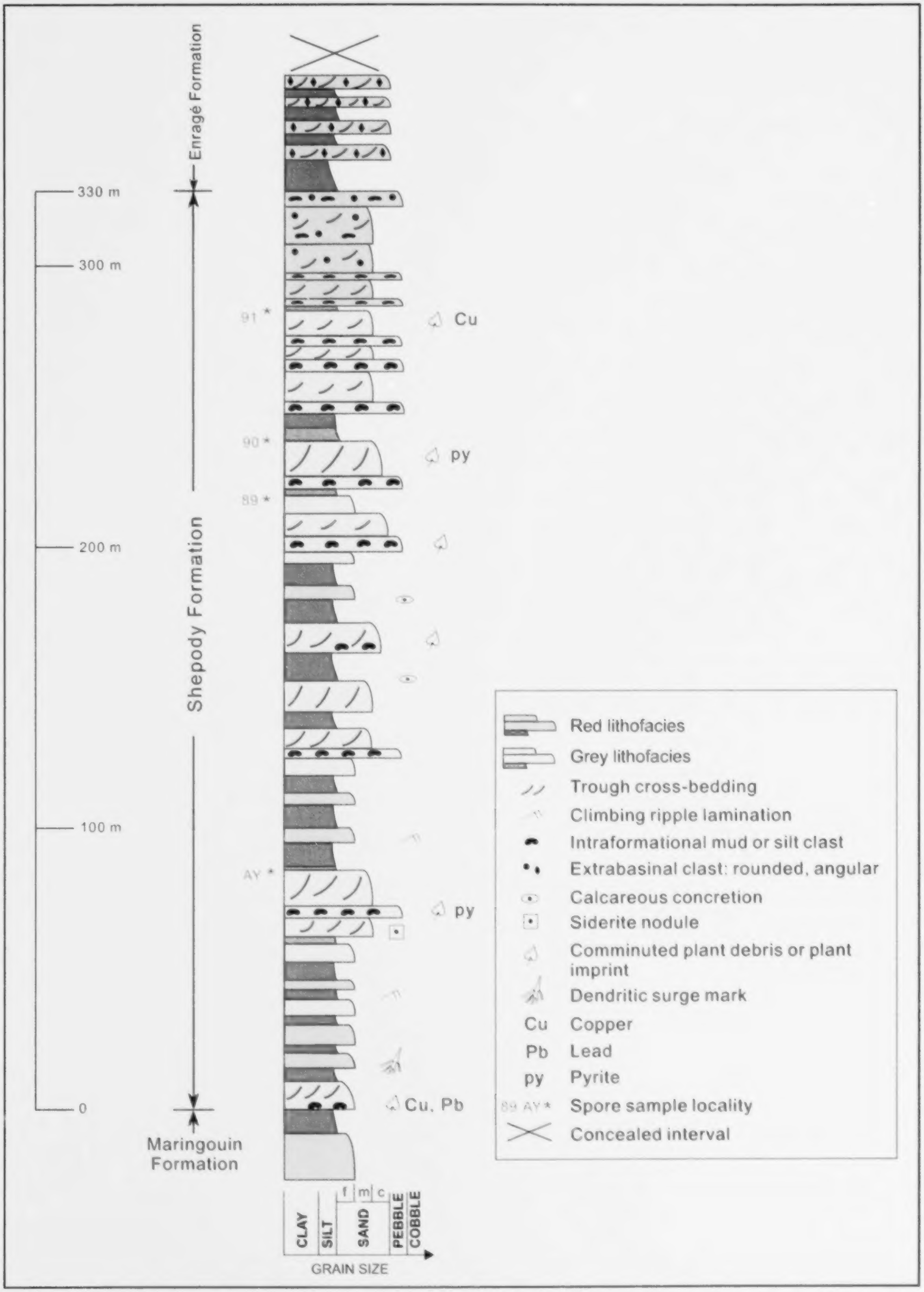

Enragé Formation
330 m
300 m
91 *
Cu
90 *
py
89 *
200 m
Shepody Formation
100 m
AY *
py
0
Cu, Pb
Maringouin Formation
f
m
c
CLAY
SILT
SAND
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Trough cross-bedding
Climbing ripple lamination
Intraformational mud or silt clast
Extrabasinal clast: rounded, angular
Calcareous concretion
Siderite nodule
Comminuted plant debris or plant imprint
Dendritic surge mark
Cu Copper
Pb Lead
py Pyrite
89 AY * Spore sample locality
Concealed interval

Figure 42. Generalized stratigraphy of the type section for the Shepody Formation at Cape Maringouin.

the present authors'. Gussow's (1953) exclusion of the upper strata that are here included is addressed below under ***Lower and Upper Boundaries***.

The formation generally coarsens from the base to the top and comprises two quite distinctive lithofacies. By virtue of the excellent exposures of the formation on Maringouin Peninsula, it is possible to map the vertical distribution of the lithofacies and to trace them laterally for several kilometres. The individual thickness of each lithofacies varies somewhat, but they can be traced along strike for at least 12 km from the Joggins shore in Nova Scotia to Cape Maringouin and a further 10 km to the southwest to Marys Cove and beyond.

The first lithofacies dominates the lower part of the formation. It comprises mainly fining-upward stacked cycles of red and lesser grey, ripple- and climbing ripple-laminated, very fine-grained to fine-grained sandstone, red siltstone, and mudstone with subordinate intervals of grey, plant-rich, trough cross-bedded sandstone, and intraformational conglomerate (Fig. 42). The finer grained cycles are typically 40 m to 75 m thick and are comparable to those in the underlying Maringouin Formation. Perfectly preserved dendritic surge marks (Fig. 43a) appear in beds of very fine-grained, ripple-laminated sandstone within the finer grained cycle near the base of the formation in the type section. The sandstone–conglomerate cycles are 5 m to 20 m thick and commonly erode deeply into the underlying mudrocks. The sandstone–conglomerate cycles become more abundant and thicker upsection.

The second lithofacies characterizes the formation from 200 m above the base to the contact with the overlying Enragé Formation. It comprises two parts: a grey lower part and a light red to pink upper part. The lower part consists of grey, multistoried, large-scale, trough and planar cross-bedded quartzose and lithic arenites, intraformational conglomerate, and grey siltstone–mudstone. Mudstones associated with this facies are almost exclusively grey. Coalified plant debris is ubiquitous in the channel sands and is commonly accompanied by pyrite or malachite mineralization. The intraformational conglomerates contain pebble-size intraclasts of limestone and calcareous mudstone and, in places, pedogenic carbonate clasts. The ratio of sandstone to conglomerate is varied. Conglomerate is particularly abundant in the type section and near Green Creek but is less common at Pecks Point and Johnson Mills. A conglomerate bed exposed south of Green Creek contains boulder-size (15–20 cm in diameter) sandy calcareous mudstone clasts. Syneresis cracks in the mudstone clasts attest to their intraformational origin. The grey sandstone–conglomerate facies attains a thickness of about 85 m in the type section (Fig. 42).

In the uppermost part of the second lithofacies, the grey sandstone–conglomerate cycles described above become predominantly light red to pink, and the siltstone and mudstone interbeds are dominantly red (Fig. 43b). These rocks were excluded from the Shepody Formation and included in the Enragé Formation by Gussow (1953) and van de Poll (1994). Apart from colour, they are lithologically identical to the underlying grey strata and are included here in the same lithofacies. Moreover, the grey–red colour boundary is not stratigraphic and cuts across bedding at Cape Maringouin and near Harvey Creek on the western side of Cumberland Basin. Together, the grey and red sandstone–conglomerate facies form a continuous, fairly thick distinctive interval. In the uppermost 50 m of this lithofacies, the pink sandstones gradually take on a greater quantity of extrabasinal clasts consisting mainly of rounded to subrounded, granular to medium-pebble quartz and lithic

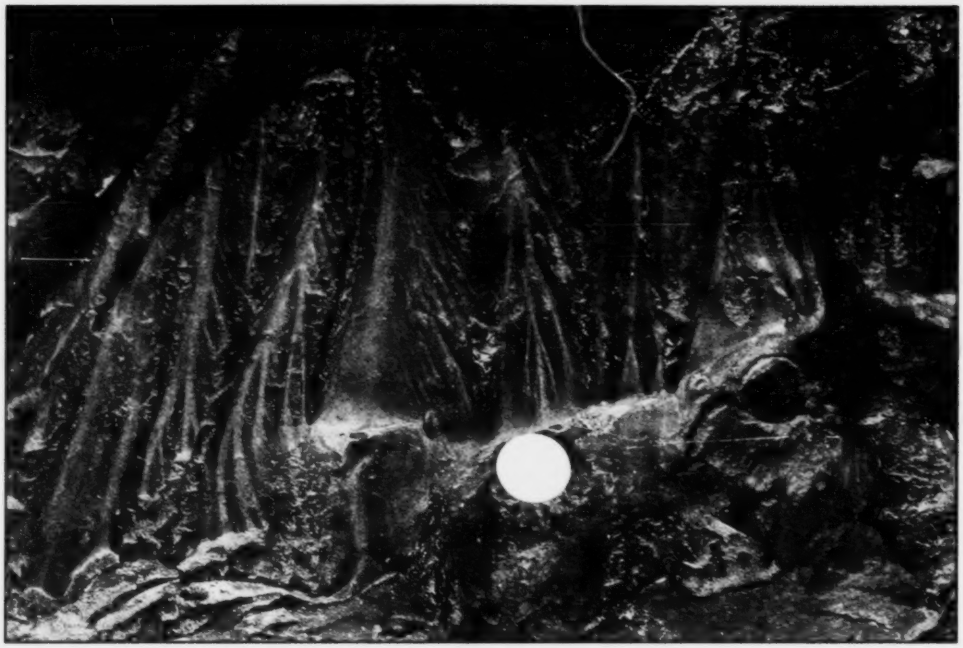


Figure 43a. Dendritic surge marks (rill marks) preserved on the underside of a sandstone bed in the Shepody Formation north of Cape Maringouin. Diameter of coin = 2 cm.

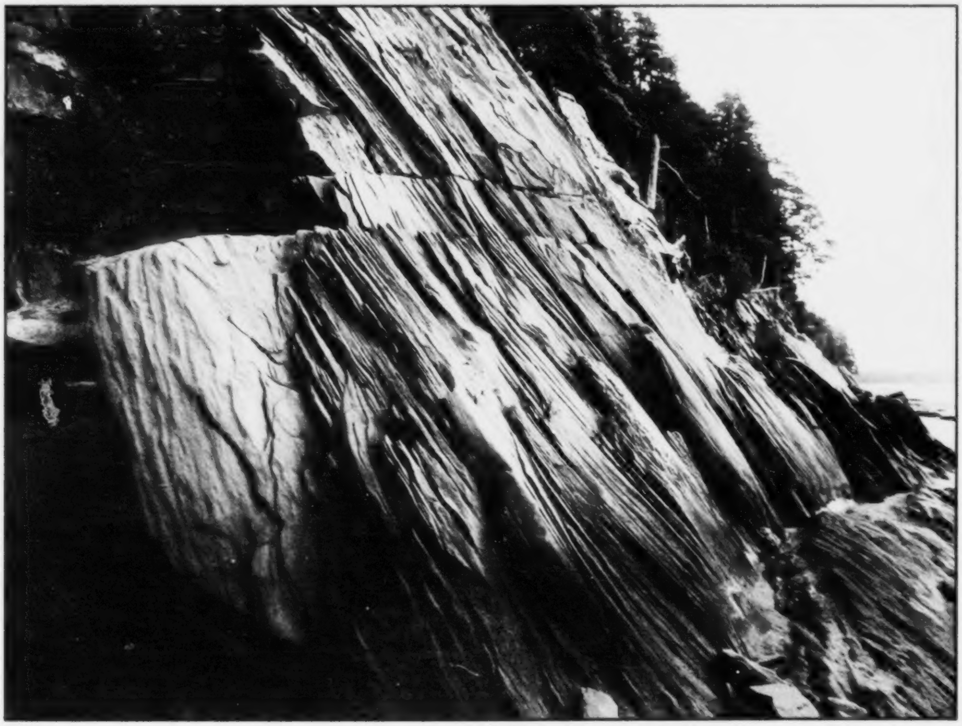


Figure 43b. Light pink to grey, medium- to coarse-grained, cross-bedded quartzose arenite in the upper part of the Shepody Formation at Marys Cove, southwest side of Shepody Bay.

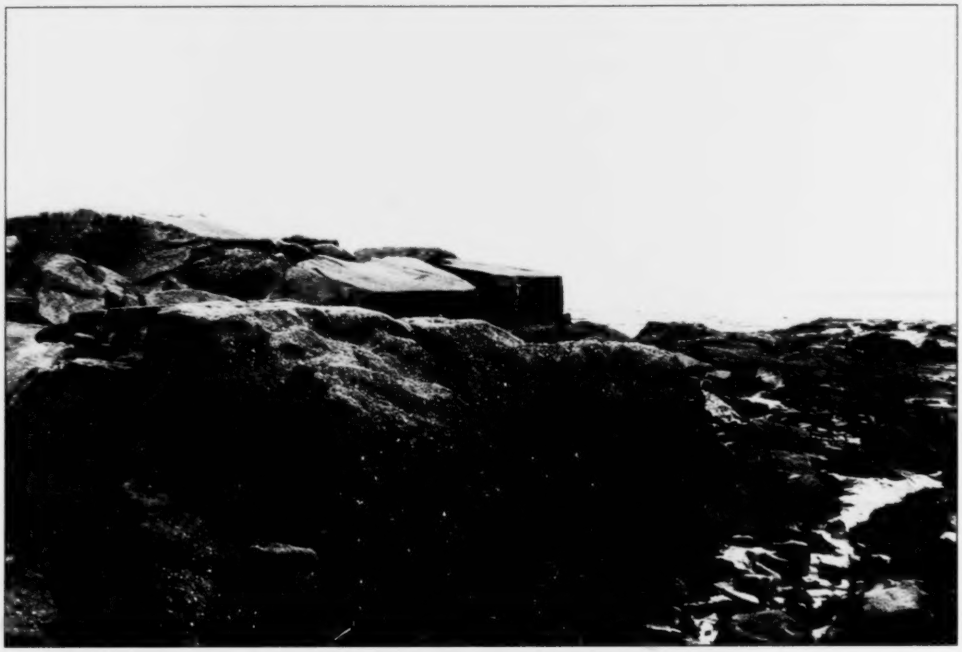


Figure 43c. Vertical bedding ridges of pink pebbly sandstone in the uppermost part of the Shepody Formation, south of Green Creek on the east side of Maringouin Peninsula.

fragments (Fig. 43c). The pebbly sandstone grades to polymictic conglomerate near the top of the formation at Cape Maringouin, Pecks Point, and Green Creek. In addition to the extrabasinal clasts, the conglomerates contain intraformational calcareous mudstone and pedogenic carbonate clasts in a sandy matrix.

Distribution and Thickness: The Shepody Formation in New Brunswick is restricted to the Cumberland Subbasin, where it is exposed on Maringouin Peninsula and in the area from Rocher Bay northeastward to Marys Cove. It also crops out in the Joggins area of Nova Scotia.

Williams et al. (1985) and Ryan and Boehner (1994) inexplicably report that the type section on the south limb of the Maringouin Anticline (Plates 5, 6) is about 700 m thick. The present authors' measured thickness of the same section is half of that, at approximately 330 m (Fig. 42). This measurement is consistent with Gussow's (1953, p. 1731) estimate of 307 m. It should be recalled that Gussow excluded the upper red to pink sandstone beds included herein in the formation. On the overturned north limb of the Maringouin Anticline near Johnson Mills, the formation is less than 200 m thick. The reduction in thickness across the fold is attributed to depositional thinning. Gussow (1953) overestimated a thickness of 700 m for the section at Cape Enrage; it is about 550 m thick there.

Lower and Upper Boundaries: The contact between the Shepody Formation and underlying Maringouin Formation is gradational and conformable, as described earlier under Maringouin Formation. The contact between the Shepody Formation and overlying Enragé Formation is also conformable, in contrast with Gussow's (1953, p. 1751) interpretation. The Shepody–Enragé contact is very well exposed at the southern end of the Shepody type section near Cape Maringouin (Fig. 37, 44). The contact is placed at the top of the highest bed of mature,

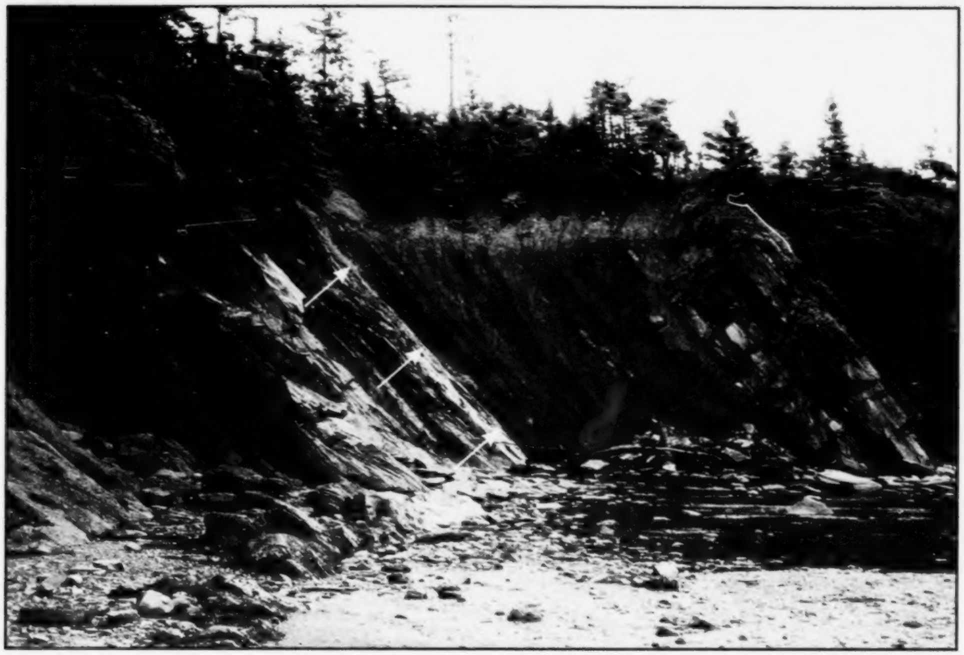


Figure 44. Contact (at arrows) between the Shepody Formation (left) and Enragé Formation (right) at the north end of the cove immediately north of Cape Maringouin.

light red sandstone or conglomerate that commonly contains small, rounded, extrabasinal quartz and lithic pebbles. The overlying Enragé Formation comprises brick red mudstone and coarse-grained, friable arkosic grits with angular quartz and potassium feldspar. The friable nature and abundance of angular quartz and potassium feldspar serve to distinguish the Enragé sandstones from the underlying Shepody sandstones. Ryan and Boehner (1994, their Fig. 2-11) draft a facies boundary between the Shepody and overlying Claremont Formation (Enragé equivalent) in the Cumberland Subbasin.

As stated above, the upper contact has been modified to a position approximately 50 m stratigraphically higher than that used by Gussow (1953) or van de Poll (1994). Although Gussow (1953, p. 1751) placed the Shepody–Enragé contact "at the highest grey, plant-bearing sandstone," well below Norman's (1941a) original contact, he did not acknowledge modifying the definition. Positioning the Shepody–Enragé contact at the grey–red colour transition rather than at the more significant lithological break has resulted in confusion concerning the stratigraphy. More importantly, it has led to misinterpretation of the nature of the Mabou–Cumberland boundary (Fig. 45).

Van de Poll (1994), for example, restricts the term 'Enragé Formation' to the upper Shepody redbeds of Norman (1941a) and assigns the overlying friable "immature unit" to the Claremont Formation after rocks in the Downing Cove section in Nova Scotia. However, the Claremont Formation is lithologically identical to and directly along strike from the Enragé Formation, the latter as described by Norman (1941a) and used herein. The "two very different lithogenetic units" to which van de Poll (1994) refers are the upper Shepody Formation and Enragé (Claremont) Formation. Van de Poll (1994) also assigns the rocks of the basal Boss Point Formation in the Alma area and at Dorchester Cape to his Enragé Formation.

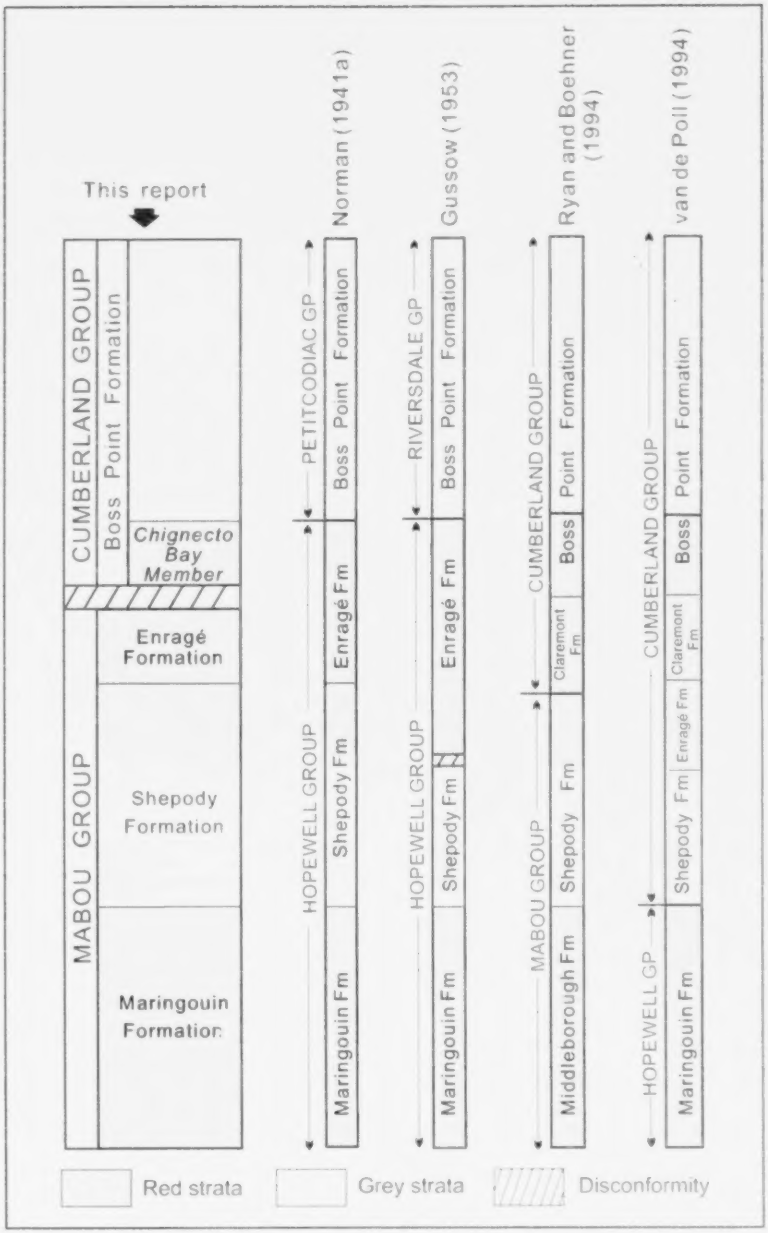

This report
CUMBERLAND GROUP
Boss Point Formation
Chignecto Bay Member
MABOU GROUP
Enragé Formation
Shepody Formation
Maringouin Formation
Norman (1941a)
PETITCODIAC GP
HOPEWELL GROUP
Boss Point Formation
Enragé Fm
Shepody Fm
Maringouin Fm
Gussow (1953)
RIVERSDALE GP
HOPEWELL GROUP
Boss Point Formation
Enragé Fm
Shepody Fm
Maringouin Fm
Ryan and Boehner (1994)
CUMBERLAND GROUP
MABOU GROUP
Boss Point Formation
Claremont Fm
Shepody Fm
Middleborough Fm
van de Poll (1994)
CUMBERLAND GROUP
HOPEWELL GP
Boss Point Formation
Claremont Fm
Enragé Fm
Shepody Fm
Maringouin Fm
Red strata
Grey strata
Disconformity

Figure 45. Historical usage of the term 'Enragé Formation' as compared with the definition of Enragé Formation used in this report.

The present authors concede that the quartzose sandstones in the upper Shepody (Enragé Formation of van de Poll 1994) and in the basal Boss Point Formation can be difficult to distinguish where stratigraphic control is lacking. However, numerous localities in the report area provide complete sections through units of the upper Mabou Group and lower Cumberland Group. For example, at Herring Cove, Dickson Brook, and Cleveland Brook in the Alma area, dusky maroon sandstones and rounded competent pebble conglomerates of the Chignecto Bay Member (Boss Point Formation) clearly overlie immature polymictic conglomerates of the Hopewell Cape Formation. At Dorchester Cape, pink to buff mature

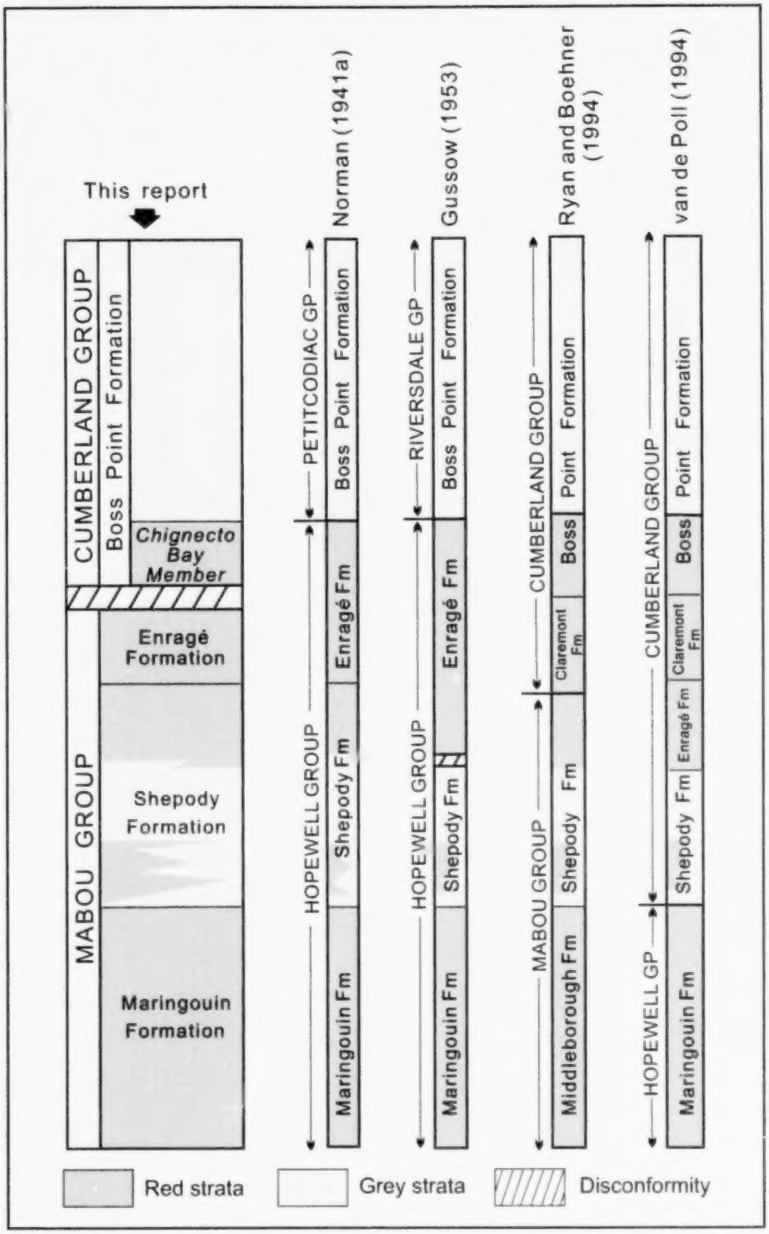

This report
CUMBERLAND GROUP
Boss Point Formation
Chigneco Bay Member
MABOU GROUP
Enragé Formation
Shepody Formation
Maringouin Formation
Norman (1941a)
PETITCODIAC GP
Boss Point Formation
HOPEWELL GROUP
Enragé Fm
Shepody Fm
Maringouin Fm
Gussow (1953)
RIVERSDALE GP
Boss Point Formation
HOPEWELL GROUP
Enragé Fm
Shepody Fm
Maringouin Fm
Ryan and Boehner (1994)
CUMBERLAND GROUP
Boss Point Formation
Claremont Fm
MABOU GROUP
Shepody Fm
Middleborough Fm
van de Poll (1994)
CUMBERLAND GROUP
Boss Point Formation
Claremont Fm
Enragé Fm
Shepody Fm
HOPEWELL GP
Maringouin Fm
Red strata
Grey strata
Disconformity

Figure 45. Historical usage of the term 'Enragé Formation' as compared with the definition of Enragé Formation used in this report.

The present authors concede that the quartzose sandstones in the upper Shepody (Enragé Formation of van de Poll 1994) and in the basal Boss Point Formation can be difficult to distinguish where stratigraphic control is lacking. However, numerous localities in the report area provide complete sections through units of the upper Mabou Group and lower Cumberland Group. For example, at Herring Cove, Dickson Brook, and Cleveland Brook in the Alma area, dusky maroon sandstones and rounded competent pebble conglomerates of the Chignecto Bay Member (Boss Point Formation) clearly overlie immature polymictic conglomerates of the Hopewell Cape Formation. At Dorchester Cape, pink to buff mature quartzose sandstones of the basal Boss Point Formation clearly rest erosively on immature mudrocks and sandstones with associated calcrete and silcrete of the Hopewell Cape Formation. On Maringouin Peninsula at Cape Maringouin, Johnson Mills, and Green Creek, the contact relationship is also distinctly evident between the friable grits and conglomerates of the Enragé Formation and the overlying dusky maroon sandstones and mudstones of the Chignecto Bay Member of the Boss Point Formation.

The lithological and stratigraphic evidence presented in this report for distinguishing and separating the Shepody and Enragé formations (Mabou Group) from the Chignecto Bay Member of the Boss Point Formation (Cumberland Group) is supported by palynological evidence. The Shepody and Enragé formations as defined herein are late Visean to early Namurian (Serpukhovian), whereas the basal Boss Point strata are late Namurian to early Westphalian A (middle Bashkirian: Fig. 9). The relevant palynological data appear below under the description of each formation and member.

Lateral Facies Relationships: The grey plant-bearing facies in the lower Shepody Formation is interpreted to be laterally related to the dominantly red sandstone strata that characterize the upper Maringouin Formation in the Sackville Subbasin and in the Moncton Subbasin north and west of Parkindale. The interpretation is based on 1) the Shepody's gradational contacts with the underlying Maringouin Formation and overlying Enragé Formation, 2) its stratigraphic position in the medial part of the Mabou Group, and 3) its restriction to the Cumberland Subbasin. The relationship of the basinal Shepody Formation with the proximal Hopewell Cape Formation is not exposed in the Cumberland Subbasin. Moreover, the existence of the compressional Dennis Beach and Lockhart Lake faults, which carry the Shepody in their hanging walls (Plate 6), indicates that the relationship can be determined solely by drilling and subsurface interpretation. The only clue to the relationship is given by palynological data, which show that the Hopewell Cape Formation ranges in age from middle Visean to early Namurian and therefore encompasses the possible age span of the Shepody Formation (Fig. 36).

Depositional Environment: The fining-upward cycles of sandstone, siltstone, and mudstone that characterize the lower part of the Shepody are interpreted as fluvial deposits generated by fairly low-competency streams analogous to those in the Maringouin Formation. Some of the sand bodies are likely sheet-wash deposits. The presence of dendritic surge marks in strata near the base of the Shepody Formation (Fig. 43a) supports this interpretation, as they appear to form on the steep banks of ephemeral streams during times of high discharge (High and Picard 1968). The predominance of grey intraformational conglomerates and stacked trough cross-bedded sandstones, together with the reduction of overbank intervals in the upper part of the unit, suggests the establishment of a larger, probably braided river system on an alluvial plain. The facts that 1) a significant part of the Shepody is grey and plant-bearing and 2) the formation is restricted to the distal part of the Cumberland Subbasin imply that the Shepody is associated with a river valley system and a more humid microclimate. The underlying, overlying, and adjacent strata of the Mabou Group are essentially red, indicating an arid or semi-arid regional paleoclimate.

Age: The Shepody Formation is latest Visean or early Namurian in age. Bell (1944) originally assigned an early Namurian age to macrofloral collections from the formation. Miospore assemblages from 21 localities (Table 3) spanning almost the entire thickness of the formation in New Brunswick have been assigned mostly an early Namurian age. Those from others localities hint at a late Visean (Brigantian) age (Dolby 1996a, 1996b, 1997a, 1997b, 2000c).

Relationship to Previous Stratigraphy: The formation as defined in this report is unchanged from that of Norman (1941a) and is equivalent to the entire Shepody Formation plus the lower 50 m of the Enragé Formation as defined by Gussow (1953). It includes both the Shepody and Enragé formations at Cape Maringouin, Pecks Point, and New Horton Flats, as defined by van de Poll (1994). The definition herein is correlative with Ryan and Boehner's (1994) Shepody Formation plus the lower 30 m of their Claremont Formation, as they include the pebbly sandstone facies near the top within the latter formation. Rocks included in the Shepody Formation are equivalent to the uppermost 211 m of Division VIII and lowermost 11 m of Division VII (Logan 1845) in the Joggins section of Nova Scotia. Bell (1944) considered these Joggins rocks to be part of the Canso Group.

Enragé Formation

Authors: Norman (1941a); revised by Gussow (1953) and van de Poll (1994).

Type Section: This formation apparently was named after Cape Enrage in Chignecto Bay, but the nearest exposures lie about 13 km to the northeast in Marys Cove. Williams et al. (1985) thus recommended the type section as exposures along the shoreline between about 0.4 km and 0.8 km north of Cape Maringouin on the western side of Maringouin Peninsula, Westmorland County (NTS 21 H/10; Plate 6). Their recommendation is accepted herein (Fig. 37).

Reference Section: A more complete section is located on the opposite, eastern side of Maringouin Peninsula between about 0.4 km and 0.5 km south-southwest of Green Creek (Fig. 46, 47) on the western shore of Cumberland Basin, Westmorland County (NTS 21 H/16; Plate 5). The formation is also well exposed along the Cumberland Basin shore at Downing Head (Fig. 6), Cumberland County, Nova Scotia (NTS 21 H/16; Ryan and Boehner 1994).

Definition and Description: The Enragé Formation as revised herein consists of reddish orange, commonly variegated, fine- to very coarse-grained arkosic sandstone, arkosic grit, pebbly grit, polymictic conglomerate, and brick red siltstone and mudstone (Fig. 48a, 48b). The formation conformably overlies the Shepody Formation and is disconformably overlain by the Boss Point Formation.

The definition herein differs from that of Norman (1941a) and Gussow (1953) with regard to placement of the upper contact. The present authors exclude the dusky maroon to reddish brown, fine-grained sandstone and siltstone immediately underlying the lowest grey sandstone bed of the Boss Point Formation in the Chignecto Bay region. Lithologically, these strata more closely resemble the maroon sandstone, siltstone, and mudstone intervals observed higher in the Boss Point Formation than they do the sandstones and mudstones of the Mabou Group. The maroon sandstone and mudstone beds have been assigned the name 'Chignecto Bay Member' of the Boss Point Formation (see ***Chignecto Bay Member,*** later). Ryan and Boehner (1994) placed analogous beds exposed at Boss Cove in the Boss Point type section into the Boss Point Formation but did not formally name them (Fig. 45).

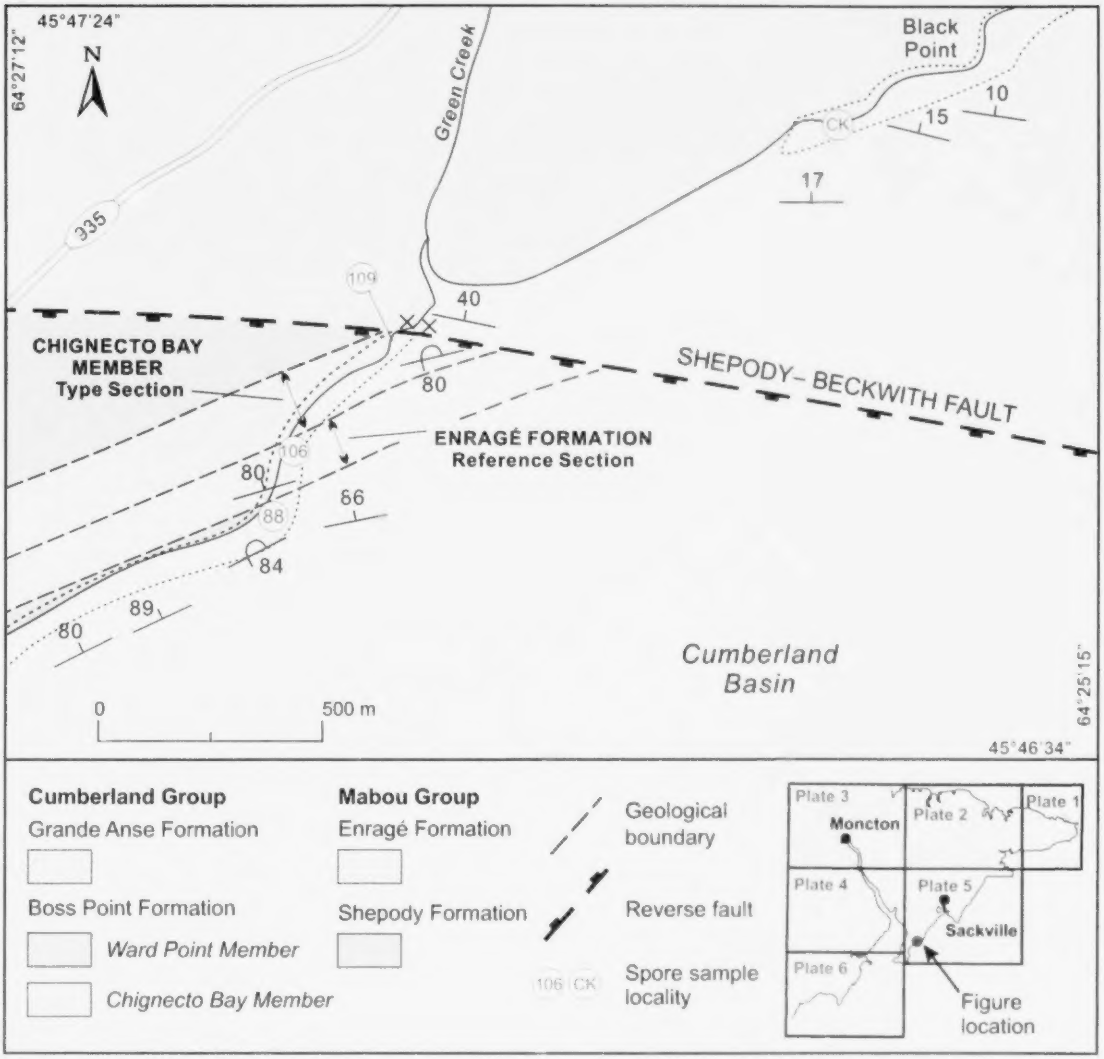

45°47'24"
64°27'12"
N
Green Creek
Black Point
335
CK
10
15
17
109
40
CHIGNECTO BAY MEMBER Type Section
SHEPODY– BECKWITH FAULT
80
ENRAGÉ FORMATION Reference Section
106
80
88
86
84
89
80
Cumberland Basin
0
500 m
64°25'15"
45°46'34"
Cumberland Group
Grande Anse Formation
Boss Point Formation
Ward Point Member
Chignecto Bay Member
Mabou Group
Enragé Formation
Shepody Formation
Geological boundary
Reverse fault
106 CK
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 46. Geology map showing the principal reference section for the Enragé Formation and type section for the Chignecto Bay Member of the Boss Point Formation, south of Green Creek on the east side of Maringouin Peninsula.

In the more restricted definition of the Enragé Formation used herein, the following units are excluded: 1) the aforesaid dusky maroon to reddish brown, fine-grained sandstone and siltstone of the Chignecto Bay Member, 2) the pink to red quartzose sandstone and conglomerate considered part of the Shepody Formation by Norman (1941a) but included in the Enragé Formation by Gussow (1953) and van de Poll (1994), and 3) the red, quartz-pebble-rich, polymictic conglomerate and associated finer lithotypes in the Moncton Subbasin that were correlated with the 'type Enragé' by Gussow (1953), McLeod and Ruitenberg (1978), and St. Peter (1993).

The revised Enragé Formation is characterized by poorly indurated, coarse- to very coarse-grained arkosic grit, polymictic conglomerate, and brick red siltstone and mudstone. The conglomerate and sandstone beds are typified by angular quartz and feldspar clasts 1 mm to

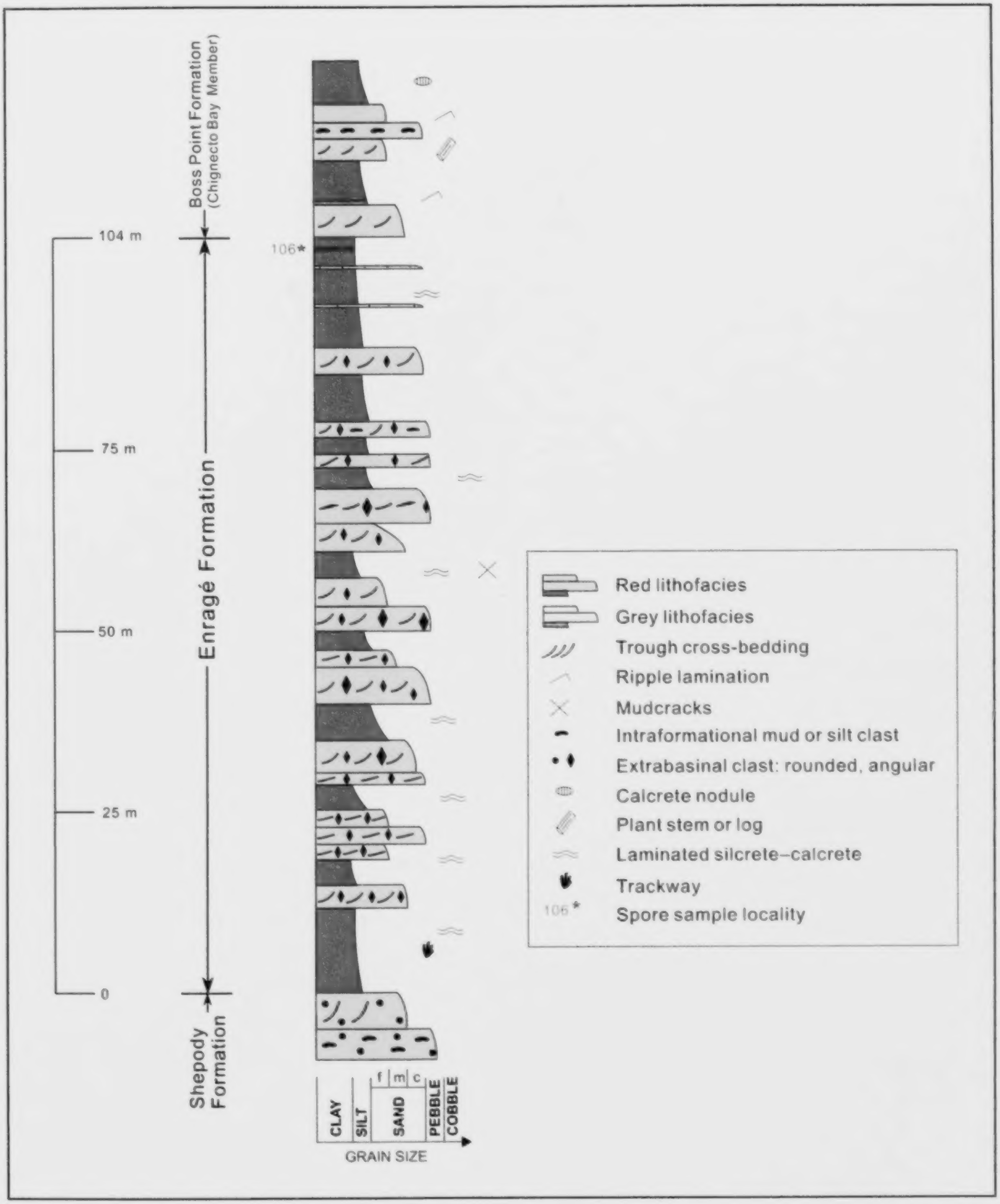

Boss Point Formation
(Chignecto Bay Member)
104 m
75 m
50 m
25 m
0
Enragé Formation
Shepody Formation
106*
CLAY
SILT
SAND
f
m
c
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Trough cross-bedding
Ripple lamination
Mudcracks
Intraformational mud or silt clast
Extrabasinal clast: rounded, angular
Calcrete nodule
Plant stem or log
Laminated silcrete–calcrete
Trackway
106*
Spore sample locality

Figure 47. Generalized stratigraphy of the principal reference section for the Enragé Formation south of Green Creek on the east side of Maringouin Peninsula.

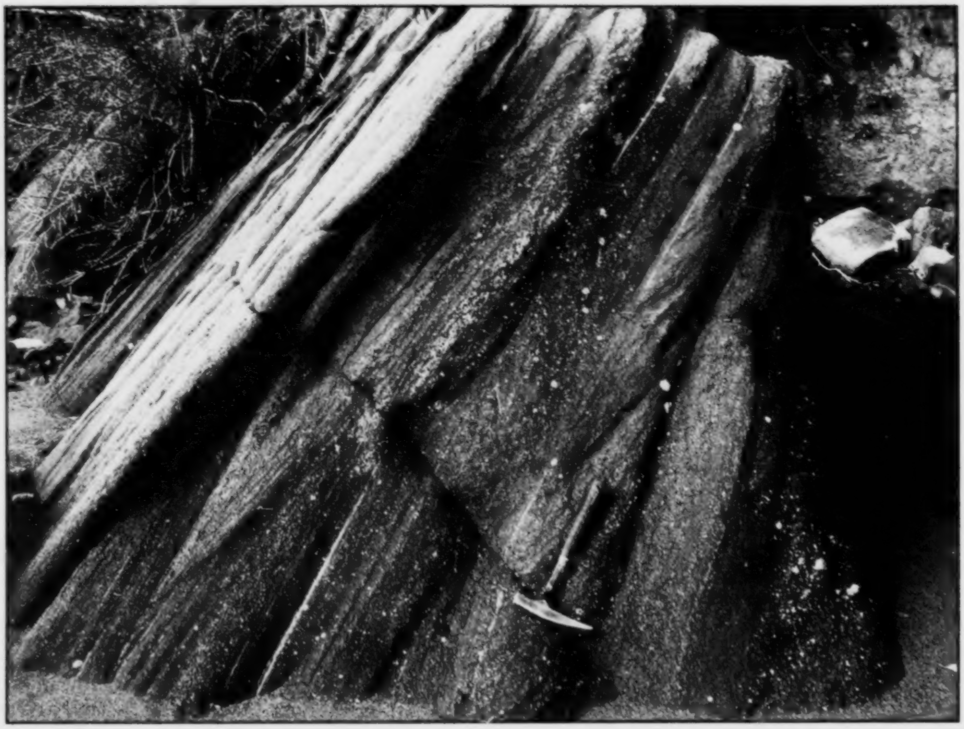


Figure 48a. Red, friable, cross-bedded, granular and coarse-grained sandstone of the Enragé Formation at Marys Cove, southwest side of Shepody Bay.

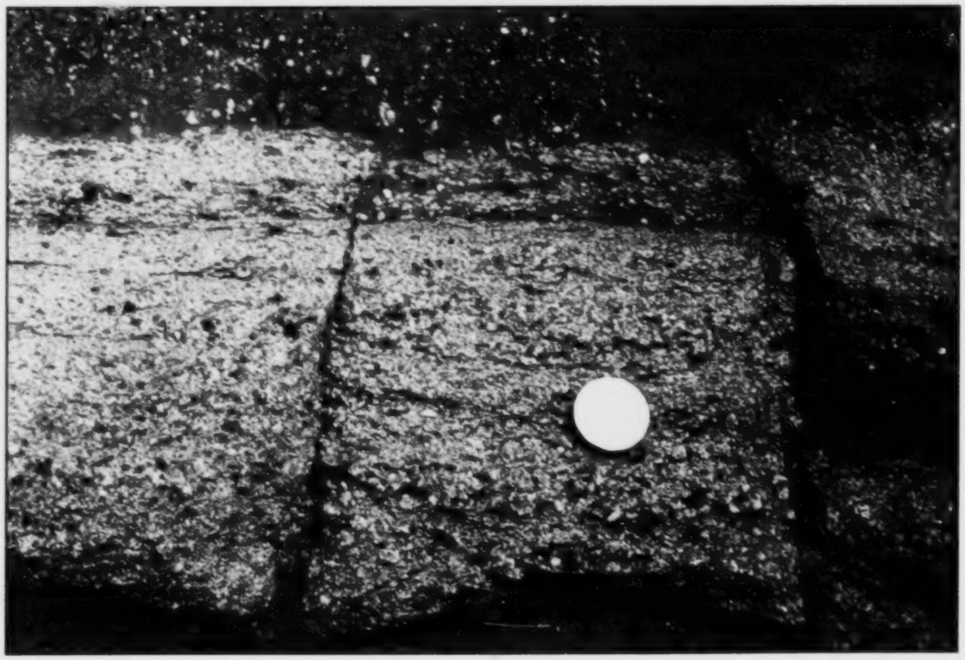


Figure 48b. Coarse-grained arkosic grit of the Enragé Formation in the cove immediately north of Cape Maringouin.

Figure 48c. Tetrapod tracks in the lower Enragé Formation south of Green Creek on the east side of Maringouin Peninsula. *Photograph courtesy of Randy Miller, New Brunswick Museum.*

3 mm in size. Sandstone intervals comprise stacked beds of conglomerate, pebbly sandstone, and sandstone typically forming fining-upward cycles 4 m to 10 m thick. Small-scale trough cross-bedding is the most common feature in the sandstone. Locally, the coarse-grained arkosic sandstone contains 10% to 40% subangular to subrounded lithic pebbles. The pebbles are up to 6 cm in diameter but average about 1.5 cm. Lithic clasts include vein quartz and grey granular quartzite (45%), granite (20%), red coarse-grained clastic rocks (20%), and felsic and mafic volcanic rocks (15%). The absence or minimal content of limestone and mudstone intraclasts and lack of associated quartzose sandstone distinguishes the Enragé conglomerates from those in the upper part of the Shepody Formation. Pebble compositions determined during this study are similar to those described for the Claremont Formation by van de Poll (1994).

Brick red siltstone and mudstone intervals commonly occupy the upper 5 m to 12 m of each fining-upward cycle in the formation. Irregular variegation caused by reduction streaks and reduction spheroids is common in the fine-grained redbeds. Calcrete nodules and rooted zones are present but not abundant. Tetrapod trackways *(Pseudobradypus ichnosp.)* occur in mudstones near the base of the formation in the reference section at Green Creek (Fig. 48c; Wood and Miller 2007). Thin (23 mm) wavy laminations of dark grey cryptocrystalline quartz and carbonate are locally a distinctive feature in the mudstones. In the Enragé Formation at Harvey Creek, thicker (up to 80 cm) horizons comprising alternating bands of grey carbonate and jasper resemble those in the Dorchester Cape Member of the Hopewell Cape Formation at Dorchester Cape. The presence of banded carbonate and jasper in the upper beds of the Enragé Formation and in the Dorchester Cape Member strongly suggest a lateral equivalency of the units.

Distribution and Thickness: The Enragé Formation and equivalent Claremont Formation in Nova Scotia are recognized only in the Cumberland Subbasin (Ryan et al. 1991). In New Brunswick the Enragé Formation is restricted to two principal geographic areas, as is the underlying Shepody Formation. The Enragé occurs on Maringouin Peninsula on both limbs of the Maringouin Anticline (Fig. 6, inset) and in the area of Rocher Bay to Marys Cove (Plates 4–6). The unit is extremely friable and generally occupies coves and other recessive topographic features.

The measured thickness in the Green Creek reference section, where the base and top are exposed, is 104 m. In the type section at Cape Maringouin and along strike at Downing Head (Fig. 6) in Nova Scotia, about 100 m of Enragé strata are present, but the upper contact is not exposed. However, basal Cumberland rocks appear in close proximity, indicating that the exposed thickness is close to the true thickness. The best exposed section west of Maringouin Peninsula occurs on the west side of Chignecto Bay at Marys Cove. There, the basal contact with the Shepody is exposed, but the upper contact with the Chignecto Bay Member of the Boss Point Formation is concealed. At Marys Cove the thickness of the formation is at least 150 m and may be greater than 200 m.

Lower and Upper Boundaries: The base of the Enragé Formation is positioned immediately below the first bed of fine- to coarse-grained arkosic sandstone, arkosic grit, or brick red mudstone. As described earlier under ***Shepody Formation***, the lithological change is abrupt but interpreted to be conformable. The lower contact is exposed in the type section near Cape Maringouin (Fig. 44), at the reference section south of Green Creek, at the mouth of Harvey Creek, and at Marys Cove. Ryan and Boehner (1994) place the lower contact of the lithologically equivalent Claremont Formation in Nova Scotia about 30 m stratigraphically lower than its position herein. Their placement is at the first appearance of extrabasinal clasts (R.J. Ryan, pers. comm. to SCJ, 1995), whereas the present authors include the extrabasinal, clast-bearing, pebbly sandstone interval in the Shepody Formation.

The contact between the Enragé Formation and overlying Boss Point Formation represents the boundary between the Mabou and Cumberland groups in the Cumberland Subbasin. The upper contact of the Enragé Formation is revised herein to a position at the *top* of the highest friable arkosic grit, or fine- to coarse-grained arkosic sandstone, or brick red variegated mudstone unit; and *below* the dusky maroon or greyish maroon, ripple-bedded siltstone or compositionally mature, fine-grained, commonly plant-bearing sandstone of the basal Boss Point Formation (Chignecto Bay Member). The marked lithological change also coincides with a significant palynological and macrofloral break at this boundary, indicating that the Mabou–Cumberland boundary is unconformable (see discussion under ***Cumberland Group***, later). In the reference section, where the Enragé–Boss Point contact is exposed, beds above and below the contact are parallel and provide no obvious evidence for an erosional unconformity (Fig. 49). However, the presence of calcrete–silcrete layers in the uppermost beds of the Enragé Formation suggests a prolonged period of exposure and non-deposition leading up to the significant mid-Namurian hiatus that separates the Mabou and Cumberland groups.

Most previous authors who studied the Mabou and Cumberland beds in New Brunswick positioned the upper contact of the Enragé Formation higher in the section than the boundary recommended herein. Placing the group boundary above the dusky maroon sandstones and

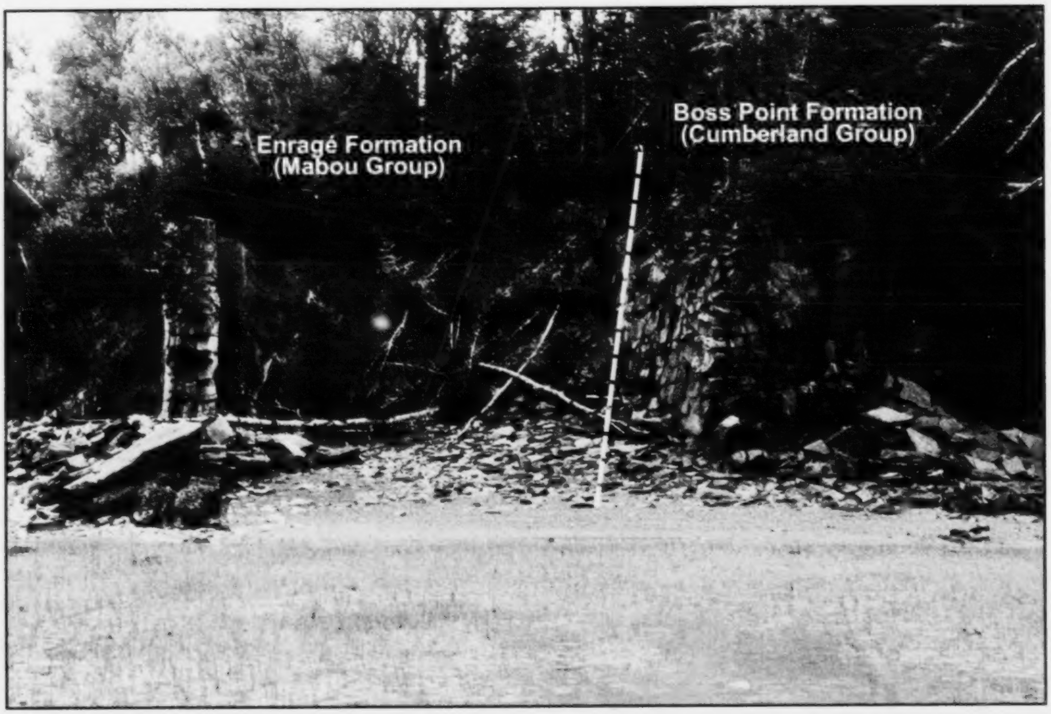


Figure 49. Disconformable contact between the Enragé Formation and Boss Point Formation (Chignecto Bay Member) south of Green Creek on the east side of Maringouin Peninsula.

siltstones (the Chignecto Bay Member as defined here) is the main reason why the regional disconformity between the groups was not previously appreciated. For example, Norman (1941a) and Gussow (1953) included the dusky maroon, ripple-bedded siltstones and sandstones above the friable arkosic grits and sandstones within the Enragé Formation, and they placed the Boss Point boundary at the base of the first significant grey sandstone. Consequently, the significant lithological break in their method of subdivision was obscured within their Enragé Formation (Fig. 45). Not surprisingly, Gussow (1953) interpreted the Enragé–Boss Point contact to be conformable.

Bell (1944) suggested a major macrofloral change between the Canso and Riversdale groups. This was problematic to Gussow (1953), because the base of the Riversdale Group in New Brunswick was placed at the base of the Boss Point Formation, whereas Bell (1944) placed it lower in the section at the base of the Claremont (Enragé) directly along strike in the Cumberland Subbasin in Nova Scotia. For Gussow, Bell's fossil evidence thus appeared to dictate a significant unconformity between the Enragé Formation and the underlying Shepody Formation (e.g., within his Hopewell Group: see Gussow 1953, his Fig. 2).

The present authors suggest an alternative hypothesis based on more recent mapping and palynological studies. Dolby (1995c, 1996a, 1996b, 1997a, 1997b, 1999a, 1999b, 2000b, 2000c, and 2005) notes a change in miospore assemblages at the stratigraphic level between the highest plant-bearing beds of the Shepody Formation (Bell's 1944 Canso Group) and the earliest plant-bearing beds of the Boss Point Formation (upper part of Bell's Riversdale Group). However, it is most improbable that any of the macroflora Bell (1944) describes from the "Riversdale Group" were collected from the red arkosic grits and conglomerates, which in this report are considered equivalent to the Enragé Formation. This suggests that the paleontological break lies between the Enragé and Boss Point formations and corresponds to the Mabou–Cumberland boundary as defined in this report.

Lateral Facies Relationships: The Enragé Formation is interpreted to be in part laterally equivalent to the upper part of the Hopewell Cape Formation (Fig. 36). The upper part of the Mabou Group is therefore represented by the Hopewell Cape Formation along the northwestern sides of the Cumberland and Sackville subbasins and in the Moncton Subbasin, whereas the Enragé Formation is restricted to the more distal part of the Cumberland Subbasin.

Depositional Environment: The Enragé Formation as defined herein, together with the near-equivalent Claremont Formation in the western part of the Cumberland Subbasin of Nova Scotia (Ryan and Boehner 1994), are geographically restricted to the central part of the Cumberland Subbasin. The Enragé Formation is characterized by a stacked sequence of fining-upward cycles of trough cross-bedded, arkosic pebble conglomerate, arkosic grit, sandstone, and variegated (dominantly red) siltstone and mudstone. The cyclicity is attributed to fluvial (probably braided stream) deposits laid down on the outer or distal part of a major alluvial fan complex. Depositional environments of coarse alluvial deposits are described by Rust (1979), Rust and Koster (1984), and Miall (1981, 1992). The Enragé Formation is the uppermost and coarsest formation of the fining-upward Mabou Group in the central part of the basin. It is interpreted as the highest energy unit in the group and so is the one with coarse detritus transported the farthest basinward. The greater transport distance of the sediment resulted in the gravels and sands becoming cleaner (more quartz and feldspar grains and less mud) than the correlated, more proximal, polylithic and muddy beds of the Hopewell Cape Formation (Fig. 36). The presence of laminated calcrete and rare associated jasper in the upper beds of the formation is interpreted as partial silicification of calcareous paleosols (e.g., see Arakel et al. 1989). The soil profiles reflect a gradual diminution in sedimentation and prolonged periods of exposure on the fan complex leading up to the mid-Namurian (Mississippian–Pennsylvanian) regional and continental unconformity.

Age: The Enragé Formation yielded spores from only one site (spore locality 106 on Plate 5) near the top of the formation at the reference section (Fig. 46, 47). The assemblage gave an age no younger than Namurian (Dolby 1997b) but, according to Dolby, was too sparse to date with confidence. At the reference section of the Claremont Formation at Downing Head in Nova Scotia, an assemblage (sample J86-4) from approximately 10 m above the base of the Claremont Formation yielded an early Namurian age (Ryan and Boehner 1994, their enclosure 1). However, that spore locality would lie in the Shepody Formation, not the Enragé or Claremont formation, if the contact between the two formations is placed 30 m higher in the section as recommended herein. The age of the Enragé can also be inferred from its stratigraphic position. It is no older than the conformably underlying latest Visean to early Namurian Shepody Formation and no younger than the overlying late Namurian C (late Yeadonian) Chignecto Bay Member of the Boss Point Formation.

Relationship to Previous Stratigraphy: The revised Enragé Formation as defined herein (Fig. 45) is equivalent to the lower part of the formation as defined by Norman (1941a). The revised formation is equivalent to only the middle part of Gussow's (1953) Enragé Formation. Similarly, the revised Enragé Formation is equivalent to only the middle part of Logan's (1845) Division VII in the Joggins section. Division VII comprises redbeds considered part of three formations: the upper part of the Shepody Formation, the entire Enragé Formation, and the Chignecto Bay Member of the Boss Point Formation. The Enragé is synonymous with the Claremont Formation of van de Poll (1994) and all but the lowermost 30 m of the Claremont Formation in the Joggins section in Nova Scotia as defined by Ryan and Boehner (1994).

Hopewell Cape Formation

Authors: van de Poll (1994); revised herein.

Type Section: The type section for this formation (Fig. 50), designated by van de Poll (1994), lies on the west side of Shepody Bay from Hopewell Cape north about 1 km to Cape Rocks, Albert County (NTS 21 H/15; Plate 4). However, it is representative only of the coarse, basin-margin strata of the formation. Gussow (1953) designated the section as the type section for the Hopewell Group, a now-abandoned name that, at the time, was applied to strata in New Brunswick equivalent to the Mabou Group in Nova Scotia.

Reference Sections*:** The cliffs at Dorchester Cape on the east side of Shepody Bay (NTS 21/15; Plate 4) are designed herein as a reference section (Fig. 51, 52). The section is representative of the more distal part of the Hopewell Cape Formation and includes the type section of the Dorchester Cape Member of the formation (see ***Dorchester Cape Member, below). Excellent exposures are also offered along streams flowing off Shepody Mountain, particularly in the section above the Lime-kiln Brook Formation along Daniels Brook west of Mountville.

Definition and Description: The Hopewell Cape Formation as defined herein comprises a sequence of reddish brown, polymictic, granule to boulder conglomerate; coarse-grained to pebbly lithic sandstone; and finer grained sandstone, red siltstone, and red mudstone. The beds are typically arranged into fining-upward sequences less than 1 m to greater than 10 m in thickness (Fig. 53). The formation is comparable with rocks referred to as 'Hopewell conglomerate' by van de Poll (1994). However, it is unnecessary to preserve that term on the basis of priority for the following reasons: 1) the name 'Hopewell conglomerate' was previously used in the literature only in its broadest sense to describe undivided conglomeritic rocks of the Hopewell Group, and 2) the lithological descriptor is misleading, as a sizable part of the formation is not conglomerate.

The formation constitutes the entire Mabou Group along the northwestern margins of the Cumberland and Sackville subbasins. It also includes the redbeds that overlie Windsor and older rocks on the southern flank of the Caledonia basement block and in the eastern Moncton Subbasin. The Hopewell Cape Formation as so defined is thus similar to the definition of the Enragé Formation of McLeod and Ruitenberg (1978) and McLeod (1980). The Enragé Formation that overlies the Shepody Formation in the Cumberland Subbasin is excluded herein from the Hopewell Cape Formation, following Norman's (1941a) original definition of the Enragé Formation. The Hopewell Cape Formation also includes coarse

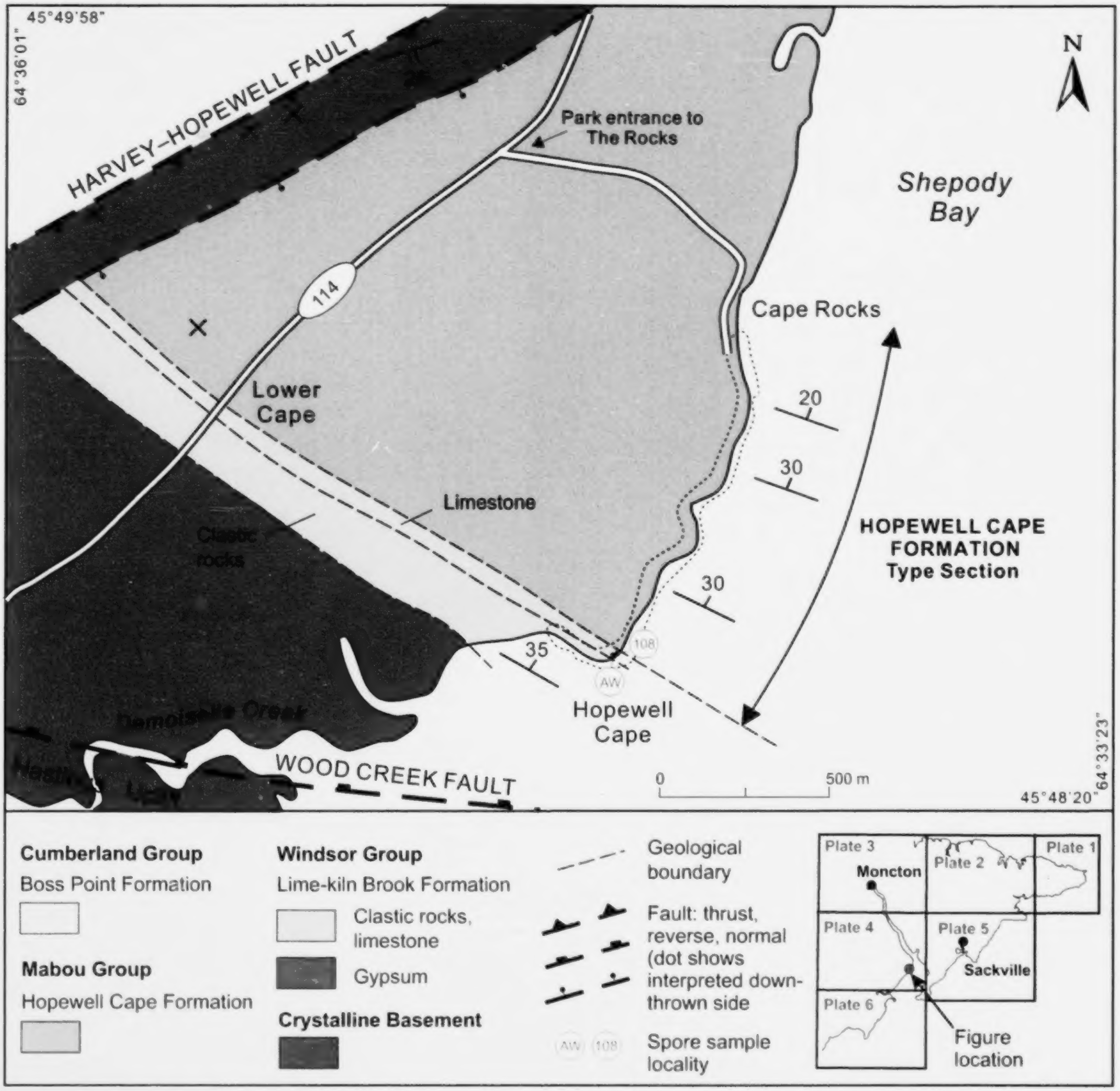
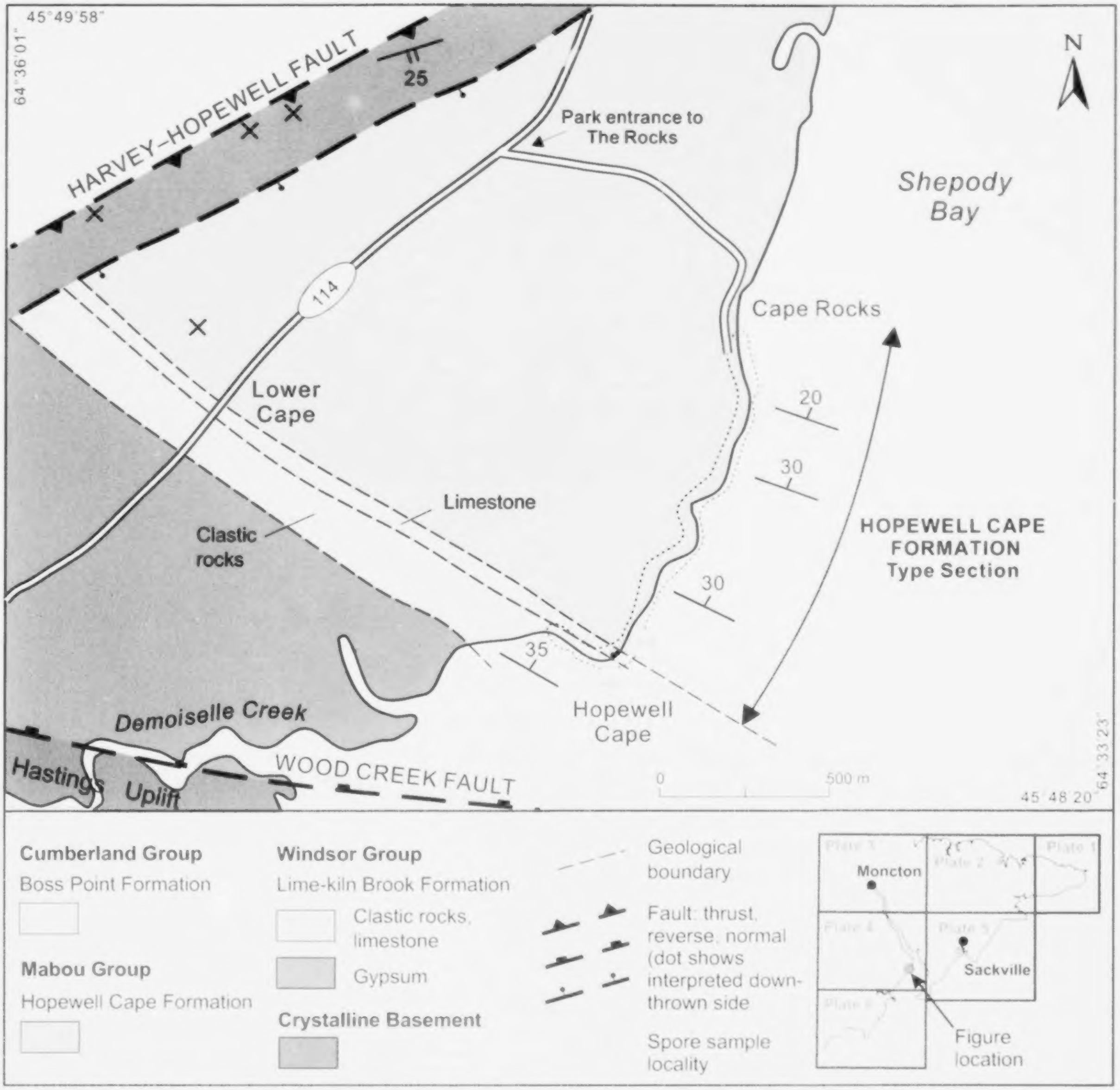

45°49'58"
64°36'01"
HARVEY–HOPEWELL FAULT
Park entrance to The Rocks
Shepody Bay
114
Cape Rocks
Lower Cape
20
30
Limestone
Clastic rocks
HOPEWELL CAPE FORMATION Type Section
30
35
108
AW
Hopewell Cape
Demoiselle Creek
WOOD CREEK FAULT
0
500 m
64°33'23"
45°48'20"
Cumberland Group
Boss Point Formation
Mabou Group
Hopewell Cape Formation
Windsor Group
Lime-kiln Brook Formation
Clastic rocks, limestone
Gypsum
Crystalline Basement
Geological boundary
Fault: thrust, reverse, normal (dot shows interpreted down-thrown side
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 50. Geology map showing the type section for the Hopewell Cape Formation from Hopewell Cape to Cape Rocks.

redbeds that lie conformably above a coarsening-upward sequence of Mabou strata in the subsurface north of Parkindale (Fig. 6).

Shepody Mountain–Daniels Brook–Chemical Brook: The formation is well exposed at and adjacent to Shepody Mountain southeast of the Harvey–Hopewell Fault (Fig. 6) in the Cumberland Subbasin. There, as at its type section at Hopewell Cape to the northeast in the Sackville Subbasin, the top of the formation is not exposed. At Daniels Brook just north of Highway 114, the Hopewell Cape Formation concordantly overlies the Lime-kiln Brook Formation and is exposed in a 500 m section in steep cliffs adjoining the brook. The lower few metres of section comprise interbedded, greyish green to reddish brown, fine-grained


45°49'58"
64°36'01"
HARVEY–HOPEWELL FAULT
25
N
Park entrance to The Rocks
Shepody Bay
114
Cape Rocks
Lower Cape
20
30
Limestone
Clastic rocks
HOPEWELL CAPE FORMATION Type Section
30
35
Demoiselle Creek
Hopewell Cape
Hastings Uplift
WOOD CREEK FAULT
0
500 m
45°48'20"
64°33'23"
Cumberland Group
Boss Point Formation
Mabou Group
Hopewell Cape Formation
Windsor Group
Lime-kiln Brook Formation
Clastic rocks, limestone
Gypsum
Crystalline Basement
Geological boundary
Fault: thrust, reverse, normal (dot shows interpreted down-thrown side
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

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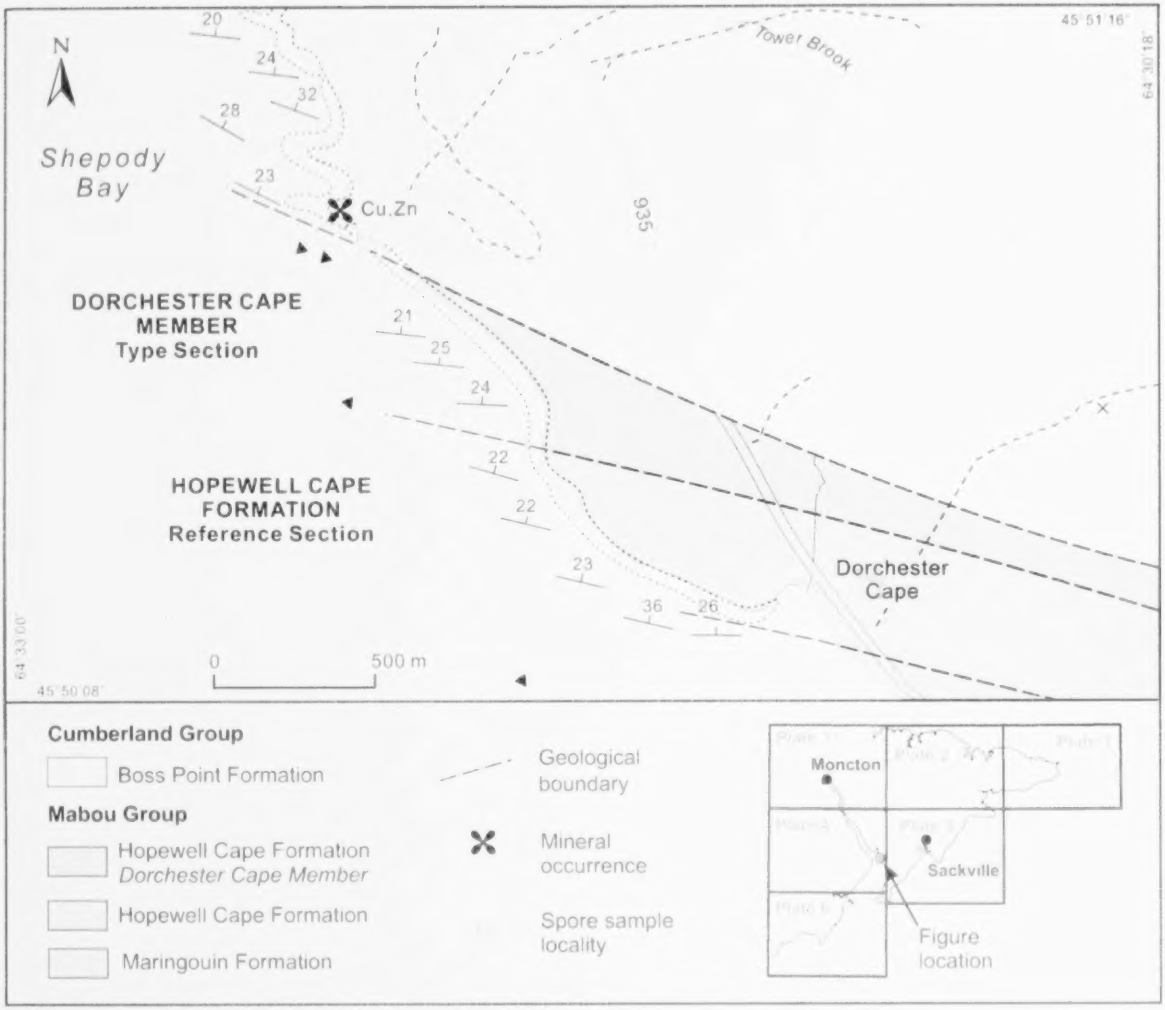


N
Shepody Bay
Cu.Zn
Tower Brook
935
DORCHESTER CAPE MEMBER Type Section
HOPEWELL CAPE FORMATION Reference Section
Dorchester Cape
20
24
32
28
23
21
25
24
22
22
23
36
26
0
500 m
45°51'16"
64°30'18"
64°33'00"
45°50'08"
Cumberland Group
Boss Point Formation
Mabou Group
Hopewell Cape Formation Dorchester Cape Member
Hopewell Cape Formation
Maringouin Formation
Geological boundary
Mineral occurrence
Spore sample locality
Moncton
Sackville
Figure location

Figure 51. Geology map showing the type section for the Dorchester Cape Member, Hopewell Cape Formation, and reference section for the Hopewell Cape Formation, at Dorchester Cape.

sandstone, siltstone, and mudstone. Farther upsection are thick, typically lenticular beds of granular lithic sandstone, pebbly grit, and cobble conglomerate. The upper part of the section is nearly exclusively interbedded pebble to cobble and cobble to boulder conglomerate. The boulders are commonly 50 cm to 110 cm in length. Farther northwest along Chemical Creek, the beds again are dominantly wedge-shaped or lenticular, pebble to boulder conglomerates. The transport direction of the detritus is consistently to the southeast, as evidenced by asymmetric current ripples in fine-grained sandstone, parting lineation in medium- to coarse-grained sandstone, cross-bed foresets, and clast imbrication in conglomerate beds. The clast lithotypes comprise abundant granite, granodiorite, pink cataclastic granite, metasiltstone, felsic volcanic, and mafic volcanic rocks, with lesser vein quartz, phyllite, schist, and intraformational clasts. Their lithologies further indicate a sediment source from the Caledonia crystalline basement to the northwest.

Dorchester Cape: The Hopewell Cape Formation is well exposed in the reference section at Dorchester Cape in the Sackville Subbasin (Fig. 53). The section includes approximately

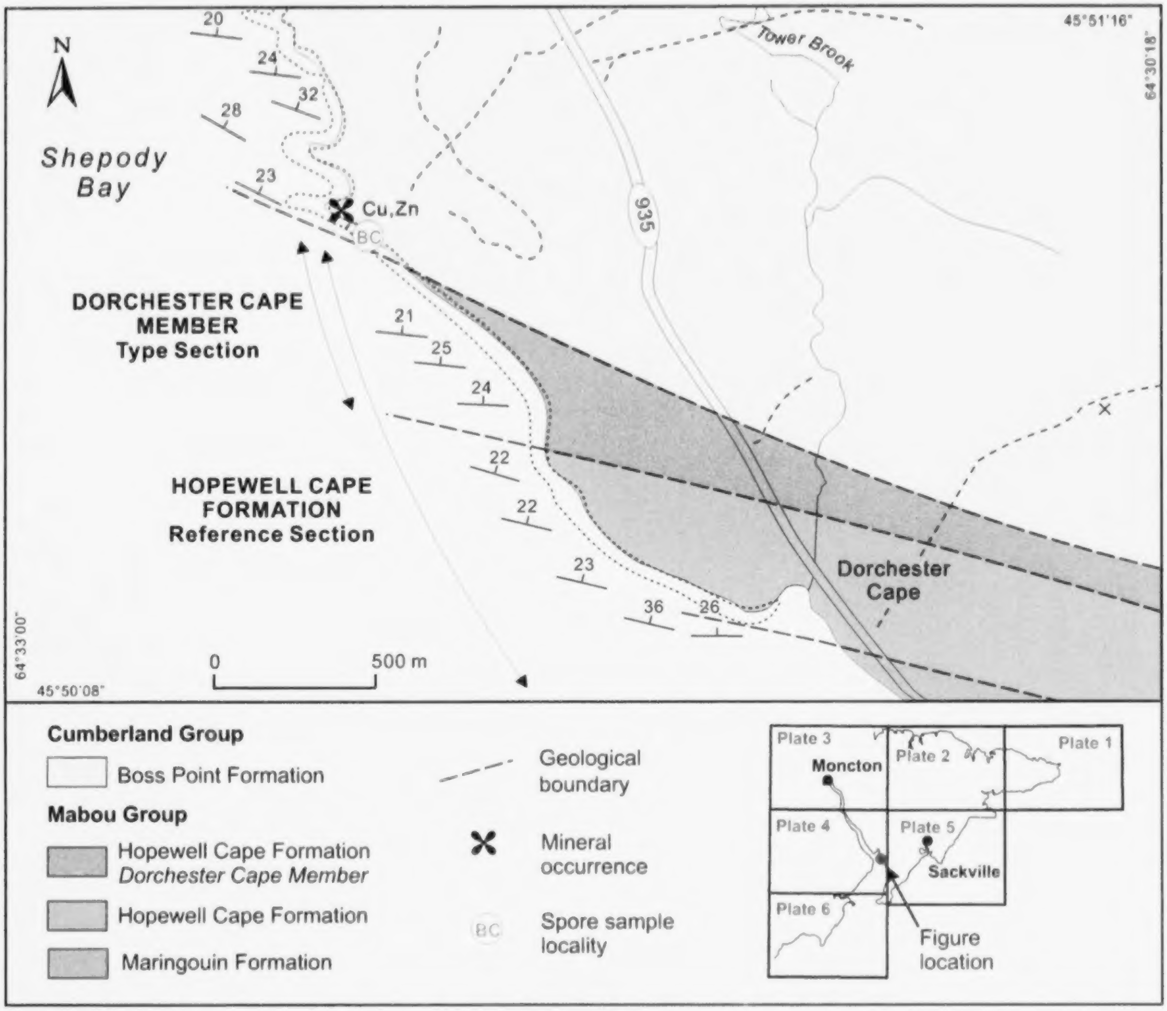

N
20
24
32
28
Shepody Bay
23
Cu,Zn
BC
Tower Brook
935
45°51'16"
64°30'18"
DORCHESTER CAPE MEMBER
Type Section
21
25
24
HOPEWELL CAPE FORMATION
Reference Section
22
22
23
36
26
Dorchester Cape
64°33'00"
45°50'08"
0
500 m
Cumberland Group
Boss Point Formation
Mabou Group
Hopewell Cape Formation
Dorchester Cape Member
Hopewell Cape Formation
Maringouin Formation
Geological boundary
Mineral occurrence
BC
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 51. Geology map showing the type section for the Dorchester Cape Member, Hopewell Cape Formation, and reference section for the Hopewell Cape Formation, at Dorchester Cape.

sandstone, siltstone, and mudstone. Farther upsection are thick, typically lenticular beds of granular lithic sandstone, pebbly grit, and cobble conglomerate. The upper part of the section is nearly exclusively interbedded pebble to cobble and cobble to boulder conglomerate. The boulders are commonly 50 cm to 110 cm in length. Farther northwest along Chemical Creek, the beds again are dominantly wedge-shaped or lenticular, pebble to boulder conglomerates. The transport direction of the detritus is consistently to the southeast, as evidenced by asymmetric current ripples in fine-grained sandstone, parting lineation in medium- to coarse-grained sandstone, cross-bed foresets, and clast imbrication in conglomerate beds. The clast lithotypes comprise abundant granite, granodiorite, pink cataclastic granite, metasiltstone, felsic volcanic, and mafic volcanic rocks, with lesser vein quartz, phyllite, schist, and intraformational clasts. Their lithologies further indicate a sediment source from the Caledonia crystalline basement to the northwest.

Dorchester Cape: The Hopewell Cape Formation is well exposed in the reference section at Dorchester Cape in the Sackville Subbasin (Fig. 53). The section includes approximately

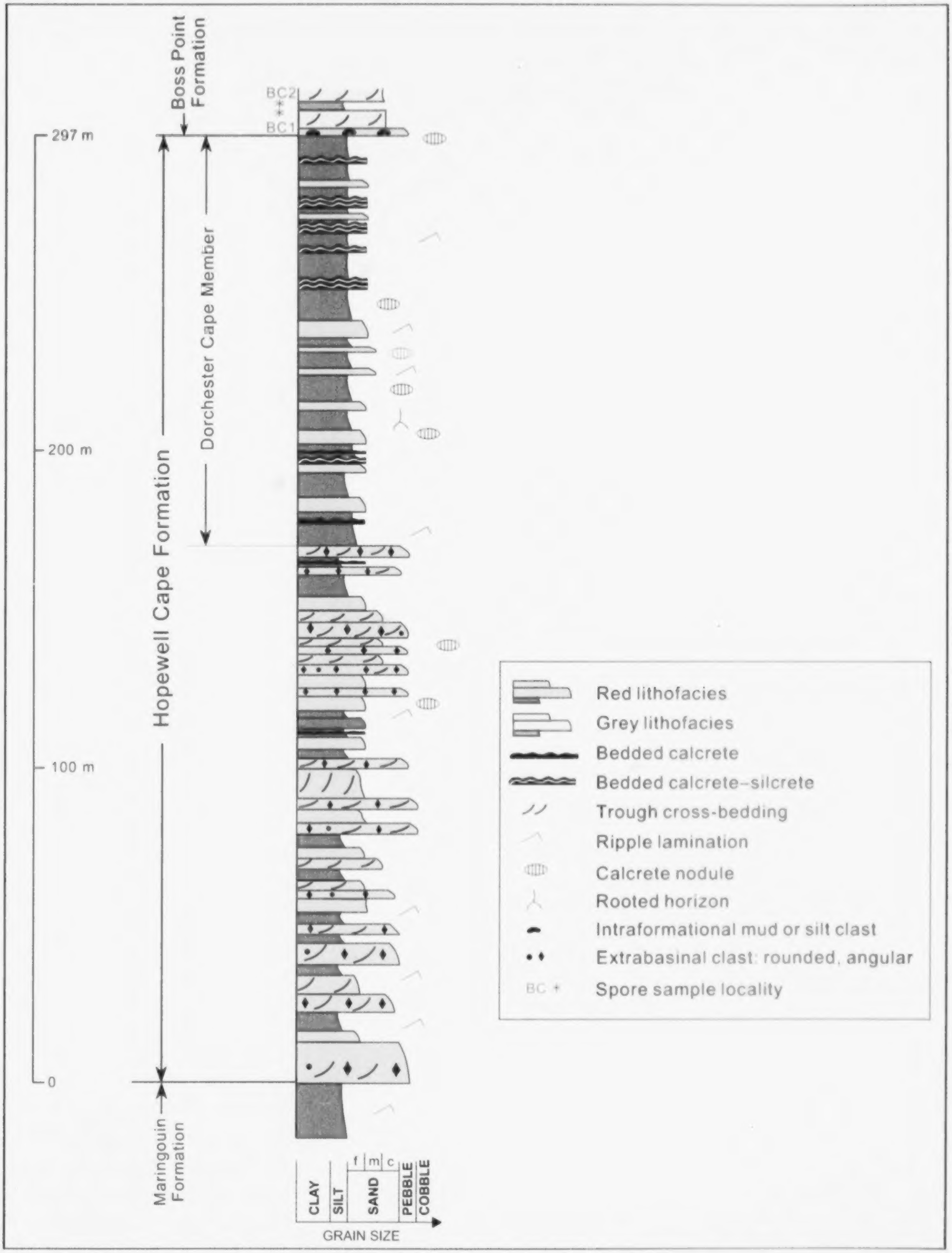

Boss Point Formation
BC2
*
*
BC1
297 m
200 m
100 m
0
Hopewell Cape Formation
Dorchester Cape Member
Maringouin Formation
f
m
c
CLAY
SILT
SAND
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Bedded calcrete
Bedded calcrete–silcrete
Trough cross-bedding
Ripple lamination
Calcrete nodule
Rooted horizon
Intraformational mud or silt clast
Extrabasinal clast: rounded, angular
BC *
Spore sample locality

Figure 52. Generalized stratigraphy of the type section for the Dorchester Cape Member (Hopewell Cape Formation) and reference section for the Hopewell Cape Formation at Dorchester Cape. Section in part after Lines et al. (1996), with permission.

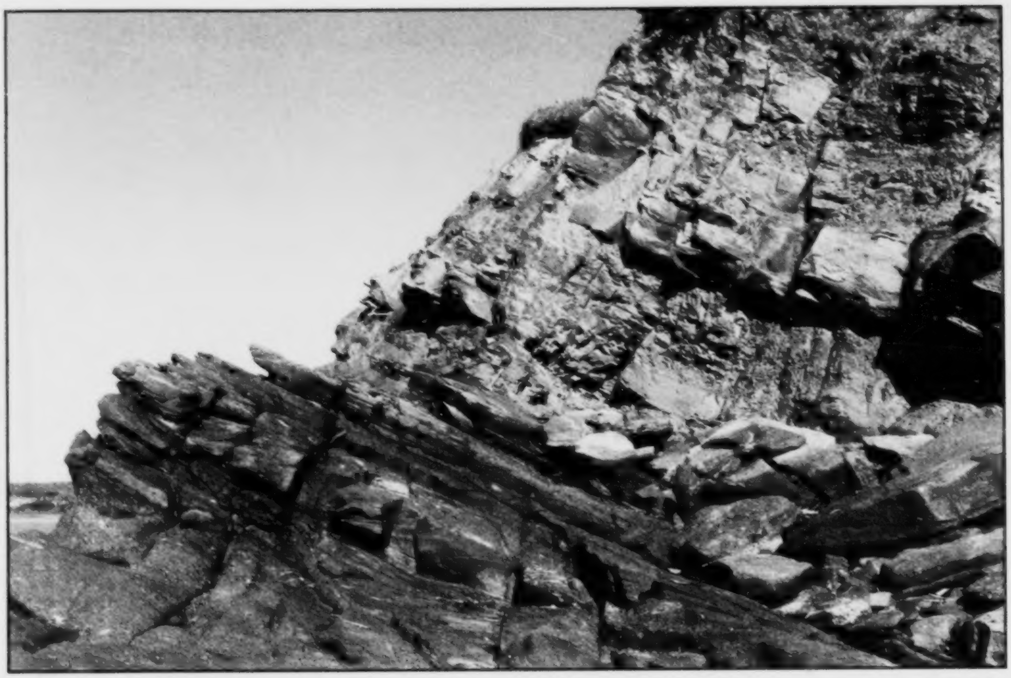


Figure 53. Maroon to red, flat- and cross-bedded, polymictic conglomerate and lithic sandstone of the Hopewell Cape Formation in its reference section at Dorchester Cape. Section here exhibits fining-upward cycles.

300 m of reddish brown to brick red conglomerate, sandstone, and mudstone (Fig. 51, 52). Repetitive fining-upward cycles become dominantly fine grained at the top (van de Poll 1973a, 1994; van de Poll and Sutherland 1976; Lines et al. 1996). The uppermost 130 m of the Dorchester Cape section is formally designated herein as the Dorchester Cape Member (described below). The lower 170 m of section includes reddish brown, poorly sorted, polymictic, pebble to cobble conglomerate; reddish brown, trough cross-bedded sandstone; and brick red and maroon, very fine-grained to fine-grained, ripple-laminated or massive sandstone, siltstone, and mudstone (Fig. 53). The conglomerate beds typically have sharp, erosive bases and commonly alternate with reddish brown, feldspathic–micaceous, fine- to coarse-grained, trough cross-bedded sandstone. The conglomerate contains subangular to subrounded clasts of foliated granitoid rocks, quartz, rhyolite, mafic volcanic rocks, and red intraformational mudstone clasts. Mineralized reduction spheroids (van de Poll and Sutherland 1976; Lines et al. 1996) are common in the fine-grained sandstones and siltstones. Calcrete nodules are also common and locally form well-developed calcrete beds 20 cm to 95 cm thick.

Van de Poll (1994, p. 199) proposed that the conglomerate and overlying fine-grained redbeds at Dorchester Cape should be redesignated as a new lithostratigraphic unit separate from the conglomerate at Lower Cape because it is a "Sackville Subbasin tectosome originating from the Westmorland basement block." He used the absence of metavolcanic clasts, abundance of plutonic clasts, and south-directed paleocurrents in the conglomerate as criteria for eliminating the Caledonia Uplift as a possible source area. However, paleocurrent data in Browne (1991, his Fig. 9.17) indicate that the conglomerates at Dorchester Cape in fact were sourced from both the north and south. The differences in clast types between the

Hopewell Cape and Dorchester Cape conglomerates are no greater than the intraformational variation within Hopewell Cape conglomerates as a whole: for example, the conglomerates contain abundant pink and green, schistose, coarse-grained arkose between Owls Head and Germantown (Plate 6), abundant phyllite and mica schist near Riverside–Albert, and abundant plutonic clasts around Hopewell Cape. Heterogeneity in the local source area is to be expected and, according to Article 24a of the North American Stratigraphic Code, a formation "may be composed of materials from one or several sources." Insufficient differences exist to separate the conglomerates at Dorchester Cape from those elsewhere in the Hopewell Cape Formation.

Dickson Brook: The Hopewell Cape Formation lies on basement on the northwest side of the Harvey–Hopewell Fault, where it is only a few metres or tens of metres thick. A representative and easily accessible section occurs at Dickson Brook about 3 km southwest of Alma. The formation there is, for the most part, finer grained than is the formation immediately south of the fault. The conglomerate beds typically carry clasts in the pebble to cobble size range, and only rarely do boulders reach a length of 25 cm to 30 cm. The conglomerates are commonly interbedded with fining-upward intervals of red muddy grits and red muddy fine- to coarse-grained lithic sandstones. Red siltstone and mudstone beds are locally abundant, particularly along Sawmill Creek about 2 km southwest of Memel Settlement. There, the basal 10 cm to 15 m of section comprises polymictic, pebble to cobble conglomerate, but the upper 30 m is mainly reddish brown mudstone with layers of discontinuous carbonate nodules and coalesced carbonate nodules. Many mudstone beds display blocky peds, carbonate rhizoconcretions, and rare mudcracks. The lithofacies at Sawmill Creek is analogous to the upper part of the Hopewell Cape Formation (Dorchester Cape Member). This suggests that beds of the Hopewell Cape Formation lying unconformably on basement northwest of the Harvey–Hopewell Fault represent only the uppermost part of the formation. A similar representation is implied by the formation lying unconformably on the Windsor Group and older strata northeast of Demoiselle Creek.

Stoney Creek: The strata in the section along Stoney Creek on the west side of Petitcodiac River are representative of Hopewell Cape rocks in the eastern Moncton Subbasin and on the Westmorland Uplift. Rocks of the Hopewell Cape Formation at Stoney Creek are almost entirely greenish grey. This atypical coloration is attributed to reduction (or the prevention of oxidation) that took place as a result of the beds lying directly over organic-rich beds of the Albert Formation. The phenomenon has been observed elsewhere in other redbed units in proximity to organic-bearing Albert rocks. The Stoney Creek section consists of massive, poorly sorted, greenish grey, polymictic, pebble to boulder conglomerate; pale green, fine- to medium-grained, lithic sandstone; greenish grey to dusky grey, pebbly coarse-grained arkosic and lithic sandstone; and bluish green, green, and red siltstone and mudstone. The conglomerates are either clast- or matrix-supported. Clasts are rounded to angular and commonly comprise over 50% chloritized tuff or schistose felsic volcanic rocks with subordinate milky quartz and mafic volcanic rocks. Clast types are not unlike the bedrock in the adjacent Caledonia crystalline basement and most likely derive from a local source.

Tan, laminated limestone and thin bands of light green to grey chalcedony occur near the top of the formation along Stoney Creek 1.2 km west of Highway 114. Individual beds of carbonate and silica range from a few centimetres to 1 m thick. Similar but much thicker horizons occur at Dorchester Cape (van de Poll 1973a, 1994) and in the Enragé Formation on the western shore of Cumberland Basin at the mouth of Harvey Creek (Plate 5). Although van de Poll (1994) considered these deposits unique to Dorchester Cape, they have been noted at many locations in southeastern New Brunswick in uppermost strata of the Mabou Group.

Distribution and Thickness: The Hopewell Cape Formation is exposed on the northwestern side of the Cumberland Subbasin from Matthews Head northeastward to Hopewell Cape. In this tract, the formation occurs largely in fault-bounded blocks on the southeastern, hanging-wall side of the Harvey–Hopewell Fault. In the northwestern corner of the Sackville Subbasin south of Upper Dorchester, the coarse Hopewell Cape beds overlie sulphates of the Lime-kiln Brook Formation (Fig. 32). South of there at Dorchester Cape, an upper tongue of the Hopewell Cape Formation overlies finer grained redbeds of the Maringouin Formation.

To the north of the Cumberland Subbasin — that is, northwest of the Harvey–Hopewell Fault — conglomerates of the Hopewell Cape Formation define a thin belt overlying crystalline rocks of the Caledonia Uplift from Alma northeastward to Demoiselle Creek. North of Demoiselle Creek and from Stoney Creek to Memramcook, the Hopewell Cape Formation is also thin and lies unconformably on Windsor and older rocks. South of Parkindale in the westernmost part of the report area, an exposed, very thin unit of Hopewell Cape strata lies over the Albert Formation and below the Boss Point Formation. North of Parkindale in the subsurface (e.g., in Wells 146 and 319; Fig. 13), the coarse Hopewell Cape Formation gradationally overlies finer grained strata correlated with the Maringouin Formation of the Cumberland and Sackville subbasins.

The thickness of the Hopewell Cape Formation is highly varied. It differs according to 1) whether the section is located in a subbasin and thus is concordant with the underlying Lime-kiln Brook or Maringouin formations, 2) whether the section lies in proximity to its upland source areas, and 3) whether, and to what degree, erosion took place below the Cumberland Group (Fig. 8, 9). About 450 m are present in the type section at Hopewell Cape in the Sackville Subbasin, but the upper part of the formation is not exposed at that locality (Fig. 50). About 800 m of strata occur in Well 330 near Dorchester (Fig. 32; Plate 4) on the northern limb of the Sackville Syncline (Plate 5), where the formation rests on the Lime-kiln Brook Formation. It is worth noting that the thickness of the Hopewell Cape Formation in Well 330 is virtually the same as the combined thickness of the Maringouin, Shepody, and Enragé formations (the complete Mabou Group) at Upper Rockport on Maringouin Peninsula. A thickness of 300 m is estimated for the section at Dorchester Cape on the south limb of the Sackville Syncline, where the Hopewell Cape Formation sits on the Maringouin Formation (Fig. 41, 51, 52).

At Dickson Brook southwest of Alma, a well-exposed, condensed section lying on the Caledonia basement and unconformably below the Boss Point Formation is only 18 m thick. Along the southern side of the Moncton Subbasin from Parkindale eastward to Memramcook, the Hopewell Cape Formation varies from a zero edge locally (e.g., at Parkindale, Dawson Settlement, and Memramcook) to a few tens of metres elsewhere. However, in the subsurface north of Parkindale, the thickness increases very abruptly to the extent that, in Well 146 just west of Colpitts Settlement (Fig. 13), it is about 350 m.

Lower and Upper Boundaries: As detailed above, the character of the lower boundary of the Hopewell Cape Formation varies, depending on the position of a given section relative to its upland or source area and to the margin of the subbasin(s). Along the southeastern flank of the Caledonia Uplift from Alma to Demoiselle Creek, the basal boundary is clearly an unconformity, as a thin Hopewell Cape section rests on Neoproterozoic basement. The unconformity is exposed at Dickson Brook southwest of Alma and along Sawmill Creek 10 km southwest of Hopewell Cape. North and northeast of Demoiselle Creek, the nature of the basal contact is equally obvious: the Hopewell Cape strata overstep all older units from the oldest Memramcook Formation to the youngest Upperton Formation.

In contrast, along the northwestern margin of the Cumberland Subbasin and adjacent Sackville Subbasin, the many-times-thicker Hopewell Cape Formation at Daniels Brook and Hopewell Cape lies concordantly on carbonates of the Lime-kiln Brook of the Windsor Group. The basal contact with the Windsor Group at the Hopewell Cape type section is particularly well exposed and is easily accessible from the beach at low tide (Fig. 35). There, the upper tongue of limestone of the Lime-kiln Brook Formation is concordantly overlain by reddish brown, coarse clastics of the Hopewell Cape Formation. The latter comprise, in ascending order 1) a thin bed of reddish brown, gritty lithic sandstone, 2) about 50 cm of greyish green, thinly interbedded, fine-grained sandstone; and pinkish grey, medium- to coarse-grained sandstone and olive siltstone, 3) about 50 cm of reddish brown, fine-grained lithic sandstone, and 4) about 150 cm of reddish brown, polymictic conglomerate containing lenticular interbeds of grit and sandstone. The olive siltstone yields spores assigned to Miospore Zone NS (Utting 1987). This supports the conclusion that the basal Mabou Group is middle Visean and therefore forms a depositionally continuous sequence with the underlying Windsor Group (away from subbasin margins).

Farther out in the Sackville Subbasin at Dorchester Cape, the lower beds of the Hopewell Cape Formation concordantly overlie and apparently intertongue with the Maringouin Formation. Similarly, in the subsurface north of Parkindale, coarse clastics of the Hopewell Cape are judged from borehole records to gradationally overlie finer grained redbeds correlated with the Maringouin Formation.

The upper contact of the Hopewell Cape Formation is exposed along Cleveland Brook on the west side of Highway 114 at a point about 250 m north of the intersection of that highway and Route No. 915 (Plate 6). There, reddish brown, immature polymictic, granular to cobble conglomerate with lesser interbeds of red muddy sandstone and sandy mudstone of the Hopewell Cape Formation are sharply and discordantly overlain by pink to brown, competent, well-rounded clast conglomerate containing interbeds of medium- to coarse-grained, well-sorted, cross-bedded, feldspathic quartzose arenite of the Chignecto Bay Member of the Boss Point Formation. The formational and group boundary appears for about 100 m, mainly along the east bank of the brook just above the waterline. Discordance at the contact is demonstrated by 1) a difference in strike of about 30° between strata of the two formations, 2) a difference in dip of 5° to 10°, and 3) lenticular bodies of red mudstone lying above the topmost polymictic conglomerates of the Hopewell Cape Formation being cut out by overlying roundstone pebble conglomerate of the Chignecto Bay Member. The same Hopewell Cape–Chignecto Bay boundary is concealed by about 1 m of covered beds, just above the waterfalls on Dickson Brook southwest of Alma (Plate 6).

The upper contact of the Dorchester Cape Member is well exposed at Dorchester Cape, where pink, thick-bedded, trough cross-bedded quartzose sandstone and greyish red conglomerate of the basal Boss Point Formation cut into the underlying red siltstone and mudstone of the Dorchester Cape Member. Pedogenic carbonate clasts in the basal conglomerate of the Boss Point Formation are almost certainly derived from the underlying calcrete-bearing redbed sequence. Browne (1991) and earlier workers (Norman 1941a; Gussow 1953; van de Poll 1973a; McLeod and Ruitenberg 1978) considered this contact to be conformable. The stratigraphical and paleontological data cited herein strongly indicate this boundary is an unconformity or disconformity (see ***Enragé Formation,*** earlier). The contact is described in more detail below in the general discussion of the Cumberland Group.

Lateral Facies Relationships: As discussed above, the Hopewell Cape Formation occupies the same stratigraphic position as the Maringouin, Shepody, and Enragé formations and accordingly is considered to be a proximal facies of these formations (Fig. 36). Thickness data for the formations support this interpretation. The most complete section of the Hopewell Cape Formation occurs in Well 330 near Dorchester (Fig. 32), where the interval of coarse proximal Hopewell Cape Formation is about 800 m thick and comprises the complete Mabou Group. At Dorchester Cape, the Mabou Group consists of the Maringouin and Hopewell Cape formations, which there have an aggregate thickness of about 900 m (Plates 4, 5). This tentative thickness estimate assumes an average dip of 30°N; it also assumes that the wide concealed section of Maringouin Formation south of the cape is not broken or repeated by faults. At Upper Rockport on the east side of Maringouin Peninsula, the Mabou Group is defined by the Maringouin, Shepody, and Enragé formations, where they have a combined thickness of about 800 m.

Depositional Environment: The Hopewell Cape Formation is interpreted to represent the proximal and medial parts of a system of coalesced alluvial fans, with the Maringouin, Shepody, and Enragé formations representing distal or basinal lithofacies in that alluvial system (Fig. 36). Supporting this interpretion are 1) the thickness of the Hopewell Cape Formation, 2) its age relative to the combined thickness and age of the Maringouin, Shepody, and Enragé formations, and 3) its geographic setting adjacent to the Harvey–Hopewell Fault.

The part of the Hopewell Cape Formation situated immediately southwest of the Harvey–Hopewell Fault appears to represent the upper part of such an alluvial fan complex. This is indicated by the presence of abundant, poorly sorted, thick-bedded, cobble to boulder conglomerate in that area. Sedimentation dominated by stream transport is indicated by the lenticularity of beds (cut-and-fill), erosive contacts of conglomerate beds on finer grained strata, occurrence of cross-beds in conglomerates and sandstones, and ubiquitous fining-upward sequences (Rust 1979; Miall 1981, 1992; Rust and Koster 1984). The formation obviously fines to the southeast: for example, the conglomerate beds at Hopewell Cape are less coarse than at Shepody Mountain, and the section at Dorchester Cape is finer grained than at Hopewell Cape. This suggests a downfan slope to the east or southeast. Van de Poll and Sutherland (1976) interpret the fining-upward cycles in the Dorchester Cape section as braided channel deposits on the periphery of an alluvial fan.

Age: A spore assemblage (spore locality 108 on Plate 4) from siltstone at the base of the formation at Hopewell Cape was assigned to Miospore Zone NS of the Visean (Fig. 15; Utting

1987). An assemblage from upper beds of the Hopewell Cape Formation at depth 75 m in Well 406 near Lower Coverdale (spore locality 107 on Plate 3), 5 m below the base of the Boss Point Formation, gave an early Namurian date (Dolby 2005). Thus, spore assemblages at the base and top of the formation suggest the Hopewell Cape Formation spans middle Visean to early Namurian time. A comparison of palynological data for the Hopewell Cape Formation with data for the Maringouin, Shepody, and Enragé formations indicates a lateral correlation of the proximal, upland Hopewell Cape Formation with the basinal, upward-coarsening Maringouin to Enragé megacycle (Fig. 36).

Relationship to Previous Stratigraphy: Various parts of this unit were previously referred to as undivided 'Hopewell Group' or 'Hopewell Conglomerate' (e.g., Flaherty and Norman 1941; Norman 1941a; Webb 1963, 1969; van de Poll 1973a, 1994; St. Peter 1993) or 'Enragé Formation' (e.g., McLeod and Ruitenberg 1978; McLeod 1980). The formation incorporates Gussow's (1953) Enragé Formation northwest of the Harvey–Hopewell fault and at Dorchester Cape and all of his undivided Hopewell Group. Bell (1927) made a correlation between the rocks adjacent to the Caledonia Uplift at Lower Cape and the Millsville conglomerate in Nova Scotia. The latter name was subsequently abandoned and the rocks reassigned to the Claremont Formation by Ryan et al. (1991) and Ryan and Boehner (1994).

Dorchester Cape Member (Hopewell Cape Formation)

Authors: New member name introduced herein.

Type Section: The type section of the Dorchester Cape Member is designated herein as the coastal cliffs at Dorchester Cape on the eastern side of Shepody Bay (Fig. 51, 52) along the section approximately 0.9 km to 1.5 km northwest of the mouth of Tower Brook, Westmorland County (NTS 21 H/15; Plate 4).

Definition and Description: The name 'Dorchester Cape Member' is applied herein to the fine-grained redbeds that occupy the uppermost 130 m of the Hopewell Cape Formation at Dorchester Cape (Fig. 51, 52, 54a). The member consists almost exclusively of red to brick red, very fine-grained to fine-grained, ripple-laminated sandstone, siltstone, and mudstone with nodular and bedded calcretes, rhizoconcretions, and distinctive banded calcrete and silcrete layers near the top (Fig. 54b). The sandstone beds rarely show wave-ripple-laminated tops overlying current-ripple-laminated bottoms, attesting to ephemeral standing water. Medium- to coarse-grained lenses of calcareous, feldspathic sandstone occur locally. In the type section, a 1 m to 2 m thick bed of intraformational conglomerate containing calcareous mud and limestone clasts is similar to those that commonly occur in the Shepody Formation. Individual calcrete beds are typically less than 1 m thick and have irregular lumpy tops (Fig. 54b). Near the top of the member, alternating beds of laminated to lensoid carbonate, grey chalcedony, jasper, and red mudstone can reach 6 m thick (Fig. 54b). Millimetre- to centimetre-scale laminae of carbonate and grey and red chalcedony are commonly interbedded with the red mudstone. Reduction spheroids are very common throughout the member.

On the west side of Petitcodiac River at Big Cape just south of Edgetts Landing, the Dorchester Cape Member comprises mainly red mudstone with several layers containing

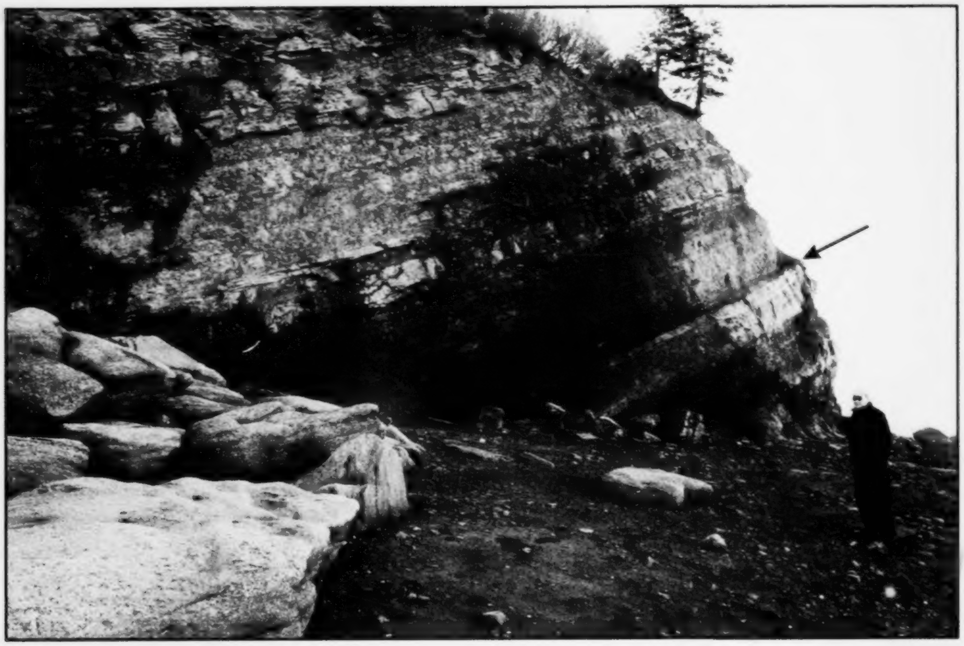


Figure 54a. Basal contact of the Dorchester Cape Member at the top of the highest polymictic conglomerate (arrow) in the Hopewell Cape Formation at the type section for the member, Dorchester Cape.

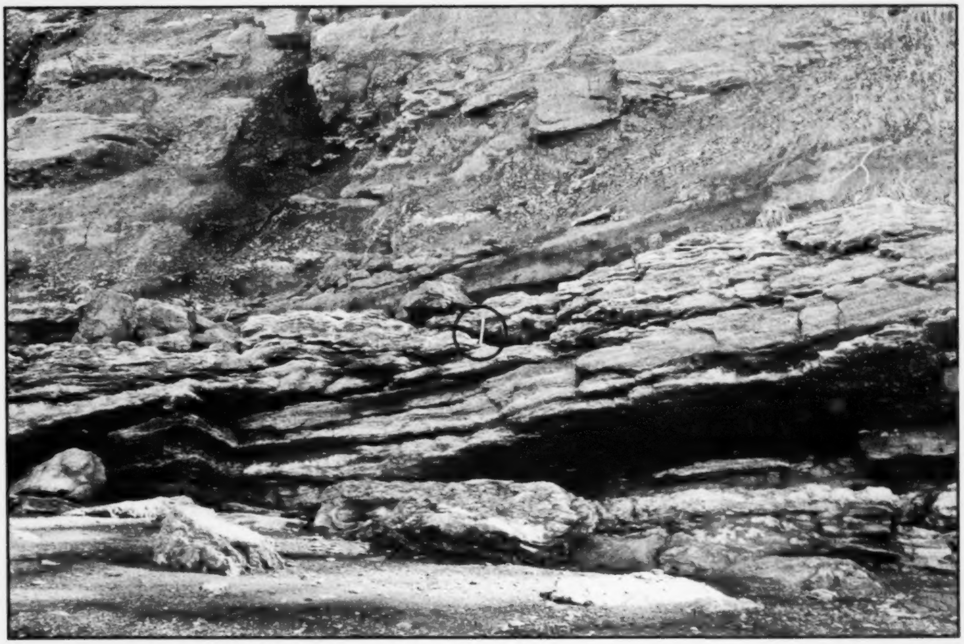


Figure 54b. Thick calcrete–silcrete layers in upper part of the Dorchester Cape Member, Hopewell Cape Formation, at the type section for the member, Dorchester Cape. Hammer for scale (circled).

isolated micritic calcite nodules and beds of lumpy coalesced calcite nodules. Irregular colour mottling that transects bedding implies the presence of rooted zones. The section also displays deep mudcracks, some filled with calcite.

Distribution and Thickness: The Dorchester Cape Member has a limited outcrop distribution and varied thickness. At the type section on the east side of Shepody Bay, it is 130 m thick. About 6.5 km northeast of there at Dorchester, it is poorly exposed along a small unnamed brook on the east side of Highway 106 (Plate 4). At Big Cape, it is about 25 m thick.

The Dorchester Cape Member was cut in Well 330 (Fig. 32), which lies about 5 km north of the type section. The drill thickness converts to a true section thickness there of about 110 m, assuming a local dip of 30°. In Well 406 at Lower Coverdale, the entire Hopewell Cape Formation is only 32 m thick. The poorly preserved cuttings from this 1919-vintage well suggest that the upper 25 m comprises mainly green to grey and lesser red, fine-grained sandstone to siltstone and red mudstone with appreciable interbeds of micritic limestone (calcrete?). The lower few metres of the unit contain beds of lithic grit and polymictic pebble conglomerate. Similarly, in Well 407 about 3 km to the southeast, the upper 11 m of the 23 m thick Hopewell Cape Formation comprises fine-grained, greyish green and reddish brown siltstone and mudstone with significant associated limestone (calcrete?). The Hopewell Cape Formation in both wells rests on crystalline basement and is overlain by the Boss Point Formation. Farther west on the Westmorland Uplift in Well 146 just west of Colpitts Settlement, coarse conglomerates of the Hopewell Cape Formation are capped by 21 m (depth interval 435–456 m) of red sandstone and mudstone that contain interbeds of limestone, interpreted from well cuttings to be caliche. The stratigraphic position of the fine-grained redbed unit above conglomerates and grits of the Hopewell Cape Formation and below the Boss Point Formation in Wells 146, 406, and 407 strongly suggests correlation of the unit with the Dorchester Cape Member.

Lower and Upper Boundaries: At the type section on Dorchester Cape, the lower contact of the Dorchester Cape Member is placed at the top of the highest polymictic conglomerate bed of the Hopewell Cape Formation (Fig. 54a). The upper contact of the Dorchester Cape Member with the overlying Boss Point Formation at Dorchester Cape is one of the best exposures of the boundary between the Mabou and Cumberland groups in New Brunswick. This contact is described in detail later in the discussion under ***Cumberland Group***.

In the section at Big Cape, the lower boundary of the Dorchester Cape Member is positioned at the top of red, coarse-grained, tabular, cross-bedded sandstone of the Hopewell Cape Formation. This section also exposes the upper contact of the Hopewell Cape Formation with buff sandstones of the Boss Point Formation.

Lateral Facies Relationships: The Dorchester Cape Member, as presently known from outcrop and boreholes, is thickest in the type area. Intervals of fine-grained calcrete-bearing redbeds, which are correlated with the Dorchester Cape Member and lie immediately below the Boss Point Formation on the Westmorland Uplift, are less than 30 m thick. The presence of silcrete and calcrete beds in the Enragé Formation at the top of the Mabou Group in the Cumberland Subbasin (see ***Enragé Formation***, earlier) suggests a lateral equivalency with the Dorchester Cape Member.

Depositional Environment: The member exhibits numerous features indicative of prolonged periods of pedogenesis, including calcrete nodules, bedded calcretes, rhizoconcretions, and well-developed silcrete horizons. Arakel et al. (1989) describe similar widespread late diagenetic silicification of Quaternary calcretes in the arid zone of western and central Australia. Van de Poll (1973a, 1994) suggests that the carbonate beds at Dorchester Cape were playa lake limestones but gives no evidence to distinguish the limestones there from non-standing-water pedogenic limestones that typically form on alluvial plains or interfluvial settings. The well-developed calcretes and silcretes within fine-grained redbeds are consistent with deposition on the distal part of an alluvial fan or on an alluvial plain. The presence of wave ripple reworking of current-rippled sandstone supports van de Poll's interpretation that at least some of the deposition may have taken place in standing water (playa lake). The Dorchester Cape Member is thinner in sections away from the type section, which could account for the reduced quantity of calcrete and silcrete beds in those sections. In places, the reduced thickness may reflect the loss of the calcrete- and silcrete-dominated upper part of the section due to erosion associated with the unconformity at the base of the Boss Point Formation.

Age: A spore assemblage recovered from rare grey mudstones in the dominantly fine-grained redbeds at the top of the Hopewell Cape Formation in Well 406 near Lower Coverdale (spore locality 107 on Plate 3) yielded an early Namurian age (Dolby 2005). The suggested correlation of the calcrete-bearing redbeds on the Westmorland Uplift with those at Dorchester Cape implies that the Dorchester Cape Member is early Namurian. An early Namurian age for the upper part of the Mabou Group is consistent with ages posted elsewhere for the Mabou Group in mainland Nova Scotia and Cape Breton Island (Neves and Belt 1970; Utting 1996 *reported in* Hamblin 2001).

Relationship to Previous Stratigraphy: Most previous workers, including Gussow (1953), McLeod and Ruitenberg (1978), and McCabe and Schenk (1982), assigned the strata at Dorchester Cape to the Enragé Formation. However, Norman (1941a), who originally defined the Enragé Formation, assigned the Dorchester Cape beds to the undivided Hopewell Group. Van de Poll (1973a) and van de Poll and Sutherland (1976) included Dorchester Cape strata in the Maringouin Formation and later applied the informal name 'Dorchester Cape beds' (van de Poll 1994).

CUMBERLAND GROUP

The name 'Cumberland Group' was introduced by Bell (1944) to describe mainly coal-bearing strata in the Joggins and Springhill coalfields in the western part of the Cumberland Subbasin in Nova Scotia. He designated the sea cliffs on the eastern shore of Chignecto Bay, from Lower Cove (Fig. 6) southwest for 43 km to Squally Point, as the type section (NTS 21 H/09, 21 H/10). As defined by Bell (1944), the Cumberland Group was unconformably to disconformably underlain by the Boss Point Formation of the Riversdale Group (now abandoned) and unconformably overlain by the Pictou Group. The only strata in New Brunswick known to contain "fossil plants belonging to the Cumberland flora" (Bell 1944, p. 20) were those of the Fern Ledges (Stopes 1914) in the Saint John area. Consequently, the Cumberland Group as defined at the time was not present in southeastern New Brunswick (see Gussow 1953; Carr 1968; van de Poll 1970, 1973a).

The most recent attempt to formally revise the Cumberland Group was undertaken by Ryan et al. (1991) and Ryan and Boehner (1994). As pointed out by these authors, Bell's (1944) group subdivisions were based primarily on their characteristic macroflora and therefore were not true lithostratigraphic units as dictated by the North American Stratigraphic Code. They accordingly adopted a set of lithological criteria for defining the Cumberland Group and in doing so expanded the definition to include all of the predominantly grey, coal-bearing strata in the Cumberland Subbasin. This necessitated abandoning the Riversdale Group and reassigning its constituent Claremont and Boss Point formations to the Cumberland Group. Their definition also required that the dominantly grey, coal-bearing strata of the Malagash Formation (originally the base of Bell's (1926, 1944) Pictou Group) be reassigned to the Cumberland Group. For the most part, the lithological criteria used by Ryan et al. (1991, p. 295) to distinguish the Cumberland Group from the Pictou Group in their type areas are not practical for defining the boundary of the Cumberland and Pictou groups in New Brunswick. Their definition, together with its strong reliance on the presence of grey and coal-bearing strata as decisive factors for assigning units to the Cumberland Group, does not appear to be applicable to strata in New Brunswick.

The Cumberland Group in New Brunswick (Fig. 8) as proposed herein is restricted to grey or red, typically texturally and mineralogically mature, fluvial sandstone-dominated sequences that overlie the Enragé or Hopewell Cape formations and underlie the Salisbury or Minto formations. Cumberland conglomerates commonly have well-rounded to subrounded pebbles and granules composed of competent lithologies such as quartz, quartzite, and felsic volcanic rocks. Coalified plant material, coalified and permineralized logs, plant casts and molds, and minor thin coal seams attest to the abundance of plant life during deposition. Although the textural and mineralogical maturity of the sandstones can be used as a general guide for defining groups of related strata in southeastern New Brunswick, these criteria admittedly may not apply throughout the Maritimes Basin.

The group comprises two formations in southeastern New Brunswick: the Boss Point Formation and the overlying and, in part, time-equivalent, Grande Anse Formation. Although the Lancaster and Tynemouth Creek formations in the Saint John area lie beyond the report area, the authors also tentatively assign those formations to the upper part of the Cumberland Group. The Enragé and Salisbury formations are not part of the Cumberland Group, as suggested during the early stages of this project (St. Peter 1992, 1993; Johnson 1996). Instead, the Enragé and Salisbury formations are assigned herein to the underlying Mabou Group and the overlying Pictou Group, respectively.

The Cumberland Group is widely distributed throughout southeastern New Brunswick and northern Nova Scotia. The group is thickest in the type section on the eastern shores of Cumberland Basin near Joggins, Nova Scotia (Fig. 6). The type section occupies the south limb of the Minudie Anticline (an extension of New Brunswick's Maringouin Anticline) and is estimated to be over 4000 m thick (Ryan and Boehner 1994, their Fig. 2-13). Directly along strike to the west at Cape Maringouin in New Brunswick, the Cumberland Group lies largely beneath the waters of Chignecto Bay; only 700 m of basal strata are exposed in that area. West of Maringouin Peninsula, the group changes strike as it crosses Chignecto Bay and follows the northeasterly trend of the Caledonia Uplift along the complexly faulted and telescoped western margin of the Cumberland Subbasin.

In the Sackville Subbasin on the south limb of the Sackville Syncline near Evans (Plate 5), the Cumberland Group (Boss Point Formation) has a thickness in excess of 2 km. The group becomes progressively thinner to the northwest in the Moncton Subbasin where a maximum thickness of 250 m was intersected in boreholes south of Moncton (Fig. 55). The thinning of Cumberland strata in this area is due partly to the influence of the Westmorland Uplift, an intrabasinal basement ridge. However, borehole data from west of the report area indicate that the group becomes thicker off the western end of the uplift into the axial part of the Moncton Subbasin. The distribution and thickness of the Cumberland Group on the New Brunswick Platform (Fig. 6) is not well known but is estimated at only a few metres to tens of metres thick.

The base and the top of the Cumberland Group are bounded by regionally significant disconformities and/or unconformities. The upper contact, the Cumberland–Pictou boundary, is discussed later under ***Pictou Group***. The lower contact, the Mabou–Cumberland boundary, is described in detail below.

The boundary between the Mabou and Cumberland groups is a significant regional unconformity or disconformity that in all probability is coincident with the boundary between the Mississippian and Pennsylvanian subsystems of the Carboniferous (Fig. 9; Hamblin 2001). The considerable palynofloral differences between the Mabou and Cumberland groups coincide with a major climate change at this boundary (Utting et al. 2005). The common occurrence of reworked Windsor–Mabou arid assemblage spores in basal sequences of the Cumberland Group such as the Boss Point Formation in New Brunswick and mainland Nova Scotia, and the Port Hood Formation on Cape Breton Island (Dolby 1996b), also hint at a regionally extensive unconformity and erosion at this boundary.

The depositional break and lack of correspondence between plant species in the Canso and Riversdale groups were previously noted by Bell (1944, p. 24) who stated it was "the most pronounced palaeontological break in the sequence of Canadian maritime Carboniferous flora." Although local unconformities at the base of the Cumberland Group were well documented in the past (e.g., Gussow 1953; Ryan et al. 1991; St. Peter 1992, 1993), the regional significance and magnitude of the unconformity has come to light only recently (e.g., Utting et al. 2005).

Palynological data indicate that the unconformity occurs in the Namurian, between early Namurian (Arnsbergian) strata of the upper Mabou Group and late Namurian (late Yeadonian) or early Westphalian strata of the basal Cumberland Group (Fig. 9, 56). The duration of the time break recorded at the unconformity at any given locality obviously depends on the amount of erosion of the Mabou Group and the timing of transgressive (diachronous) overstep by the Cumberland Group.

In the Sackville Subbasin, a slight angular discordance is recorded at this boundary at Dorchester Cape. There, the base of the Cumberland Group is marked by a conglomerate bed containing calcrete clasts derived from the underlying red mudrocks and interbedded calcretes–silcretes of the Mabou Group. In the axial part of the Cumberland Subbasin, no angular discordance is noted, and it is possible that the unconformity is represented by non-deposition rather than erosion.

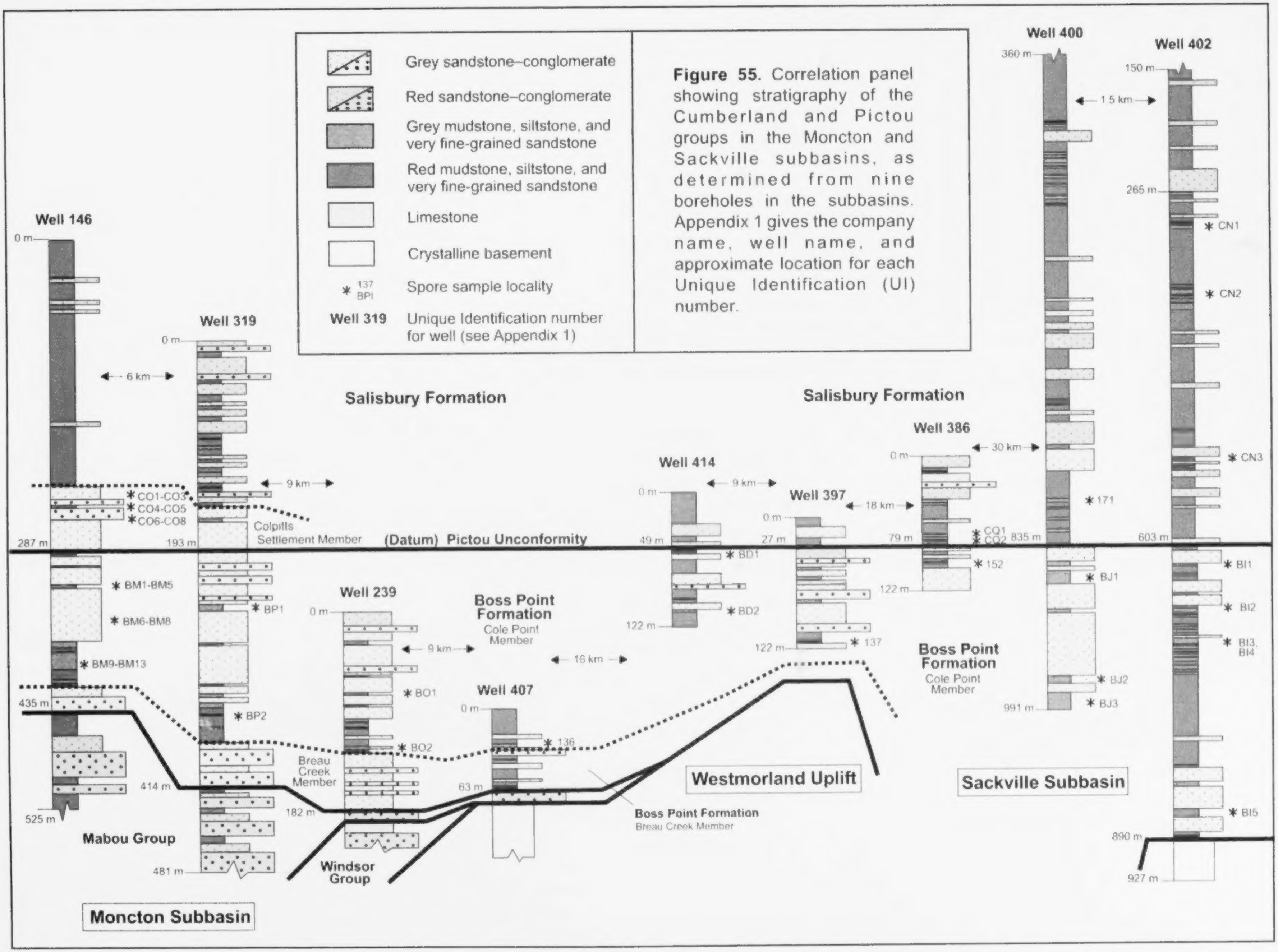
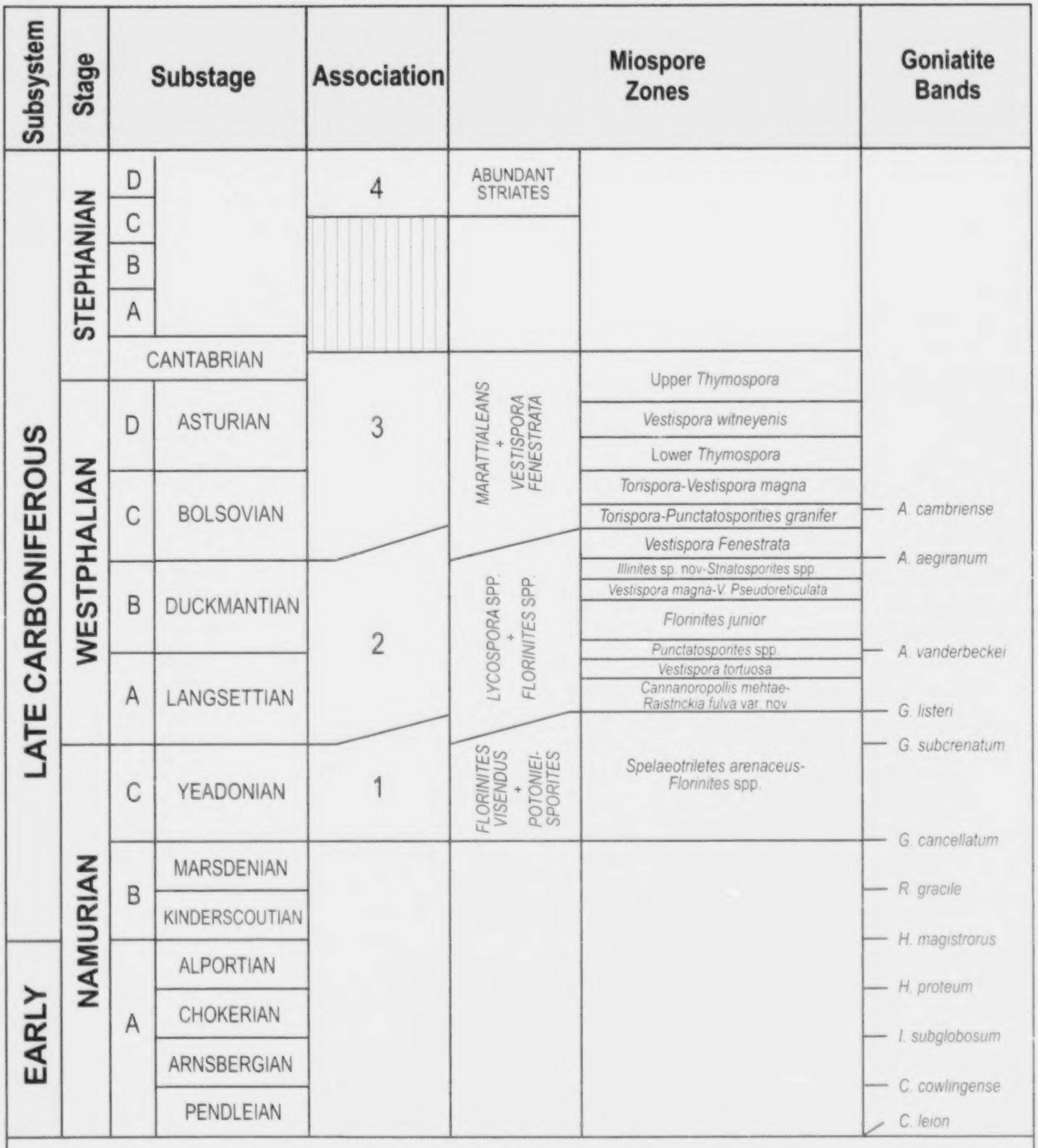


Figure 55. Correlation panel showing stratigraphy of the Cumberland and Pictou groups in the Moncton and Sackville subbasins, as determined from nine boreholes in the subbasins. Appendix 1 gives the company name, well name, and approximate location for each Unique Identification (UI) number.

Grey sandstone–conglomerate
Red sandstone–conglomerate
Grey mudstone, siltstone, and very fine-grained sandstone
Red mudstone, siltstone, and very fine-grained sandstone
Limestone
Crystalline basement
137 BPI
Spore sample locality
Well 319
Unique Identification number for well (see Appendix 1)
Well 146
0 m
287 m
435 m
414 m
525 m
CO1-CO3
CO4-CO5
CO6-CO8
BM1-BM5
BM6-BM8
BM9-BM13
6 km
Well 319
0 m
193 m
481 m
BP1
BP2
9 km
Colpitts Settlement Member
Salisbury Formation
(Datum) Pictou Unconformity
Well 239
0 m
182 m
BO1
BO2
9 km
Breau Creek Member
Boss Point Formation
Cole Point Member
16 km
Well 407
0 m
63 m
136
Mabou Group
Windsor Group
Moncton Subbasin
Well 414
0 m
49 m
122 m
BD1
BD2
9 km
Well 397
0 m
27 m
122 m
137
18 km
Westmorland Uplift
Boss Point Formation
Breau Creek Member
Salisbury Formation
Well 386
0 m
79 m
122 m
CQ1
CQ2
152
30 km
Boss Point Formation
Cole Point Member
Well 400
360 m
835 m
991 m
171
BJ1
BJ2
BJ3
1.5 km
Well 402
150 m
265 m
603 m
890 m
927 m
CN1
CN2
CN3
BI1
BI2
BI3, BI4
BI5
Sackville Subbasin


Subsystem
Stage
Substage
Association
Miospore Zones
Goniatite Bands
LATE CARBONIFEROUS
EARLY
STEPHANIAN
D
C
B
A
CANTABRIAN
WESTPHALIAN
D
ASTURIAN
C
BOLSOVIAN
B
DUCKMANTIAN
A
LANGSETTIAN
NAMURIAN
C
YEADONIAN
B
MARSDENIAN
KINDERSCOUTIAN
A
ALPORTIAN
CHOKERIAN
ARNSBERGIAN
PENDLEIAN
4
3
2
1
ABUNDANT STRIATES
MARATTIALEANS + VESTISPORA FENESTRATA
LYCOSPORA SPP. + FLORINITES SPP.
FLORINITES VISENDUS + POTONIEI-SPORITES
Upper Thymospora
Vestispora witneyenis
Lower Thymospora
Torispora-Vestispora magna
Torispora-Punctatosporities granifer
Vestispora Fenestrata
Illinites sp. nov-Striatosporites spp.
Vestispora magna-V. Pseudoreticulata
Florinites junior
Punctatosporites spp.
Vestispora tortuosa
Cannanoropollis mehtae-Raistrickia fulva var. nov
Spelaeotriletes arenaceus-Florinites spp.
A. cambriense
A. aegiranum
A. vanderbeckei
G. listeri
G. subcrenatum
G. cancellatum
R. gracile
H. magistrorus
H. proteum
I. subglobosum
C. cowlingense
C. leion

Goniatite bands after Dolby (1999b). Late Cantabrian–late Stephanian C hiatus as proposed by Wagner and Lyons (1995).

Figure 56. Palynological zonation of the late Early and Late Carboniferous for New Brunswick and Nova Scotia, modified from informal, unpublished zonation of Dolby (1996a). Early–Late Carboniferous boundary position is from Lane et al. (1999) and Heckel and Clayton (2006).

Boss Point Formation

Authors: Bell (1914); revised by Bell (1944) and Browne (1991).

Type Section: The type section encompasses Boss Point (Fig. 6), extending from Lower Cove to Downing Head (Fig. 6) on the eastern shore of Cumberland Basin, Cumberland County, Nova Scotia (NTS 21 H/09). Browne (1991) limits the type section to the exposures from the southern end of Boss Cove southward to the northern end of the first small bay north of Lower Cove.

Reference Sections: Ryan et al. (1991) designate exposures along Wallace River between Middleborough and North Middleborough, Cumberland County (NTS 11 E/13), as a reference section in Nova Scotia. Williams et al. (1985) designate Dorchester Cape (NTS 21 H/15) and Cape Maringouin (NTS 21 H/10, 21 H/16), Westmorland County, as well as Big Cape near Edgetts Landing, Albert County (NTS 21 H/15), as reference sections in New Brunswick (Fig. 57, 58).

Definition and Description: Four informal members are recognized within the Boss Point Formation in New Brunswick. They are referred to herein as the Chignecto Bay, Breau Creek, Cole Point, and Ward Point members.

The *Chignecto Bay Member* consists of dusky maroon to maroonish grey, ripple-laminated siltstone and mudstone and very fine- to medium-grained sandstone. It characterizes the base of the formation in the Chignecto Bay area. North of the Harvey–Hopewell Fault along the eastern margin of the Caledonia Uplift, the Chignecto Bay Member is overlain by the *Breau Creek Member*, which comprises abundant quartz-pebble-rich conglomerate and lesser grey to olive green and locally light red sandstone and grey to reddish brown mudstone and siltstone. The predominantly mature, competent pebble conglomerate and sandstone of the Breau Creek Member characterize the base of the formation in the Sackville and Moncton subbasins. The Breau Creek Member is succeeded by the *Cole Point Member*, which is dominated by multistoried grey sandstones and pebbly sandstone with minor grey and rare red mudrocks. The Breau Creek and Cole Point members constitute the majority of Boss Point Formation exposures in New Brunswick and are the only members in the Sackville and Moncton subbasins. In the Cumberland Subbasin south of the Harvey–Hopewell and Shepody–Beckwith faults, the basal Chignecto Bay Member is overlain by the *Ward Point Member*. It comprises alternating braidplain and lacustrine deposits (Browne 1991; Browne and Plint 1994) characterized by multistoried units of predominantly grey, fluvial, trough cross-bedded sandstone intercalated with very fine-grained sandstone, grey siltstone, and silty mudstone; and minor lacustrine limestone, organic-bearing limestone, and thin coal seams (Browne 1991; Browne and Plint 1994). The Chignecto Bay and Ward Point members comprise the Boss Point type section in the western Cumberland Subbasin in Nova Scotia.

The Chignecto Bay and Ward Point members in the Cumberland Subbasin are considered largely equivalent to the Breau Creek and Cole Point members in the Moncton and Sackville subbasins on the basis of their stratigraphic position. Although the Ward Point and Cole Point members are both dominated by grey, multistoried channel sands, the latter member contains no organic-bearing limestone or lacustrine units. The Cole Point Member also contains spore assemblages, suggesting it may be, in part, time-equivalent to the Grande Anse Formation on

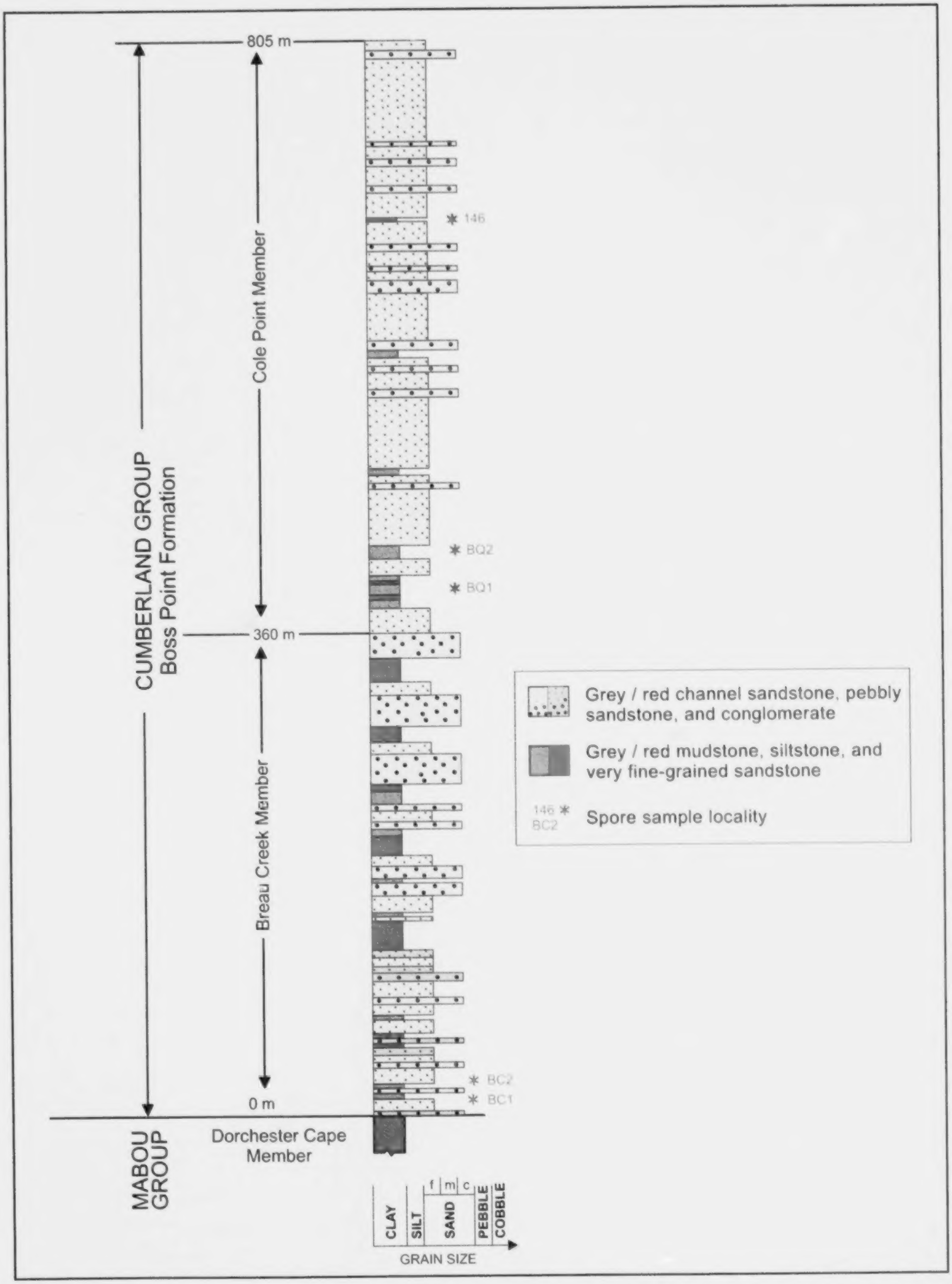

805 m
Cole Point Member
CUMBERLAND GROUP
Boss Point Formation
✱ 146
✱ BQ2
✱ BQ1
360 m
Breau Creek Member
✱ BC2
✱ BC1
0 m
MABOU GROUP
Dorchester Cape Member
Grey / red channel sandstone, pebbly sandstone, and conglomerate
Grey / red mudstone, siltstone, and very fine-grained sandstone
146 ✱ BC2
Spore sample locality
CLAY
SILT
SAND
f
m
c
PEBBLE
COBBLE
GRAIN SIZE

Figure 57. Generalized stratigraphy of the Breau Creek and Cole Point members of the Boss Point Formation at Dorchester Cape, modified after Browne (1991).

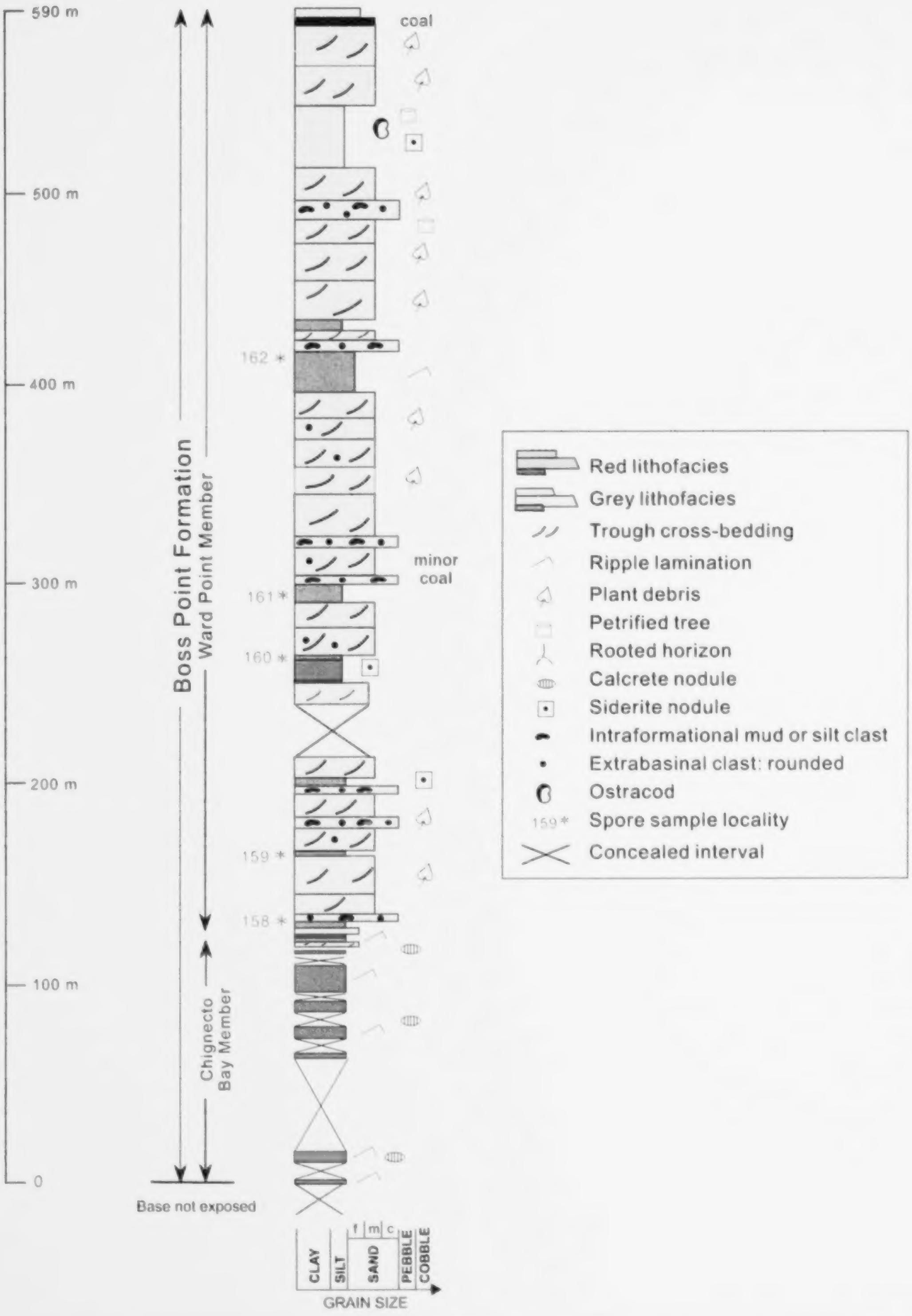

590 m
500 m
400 m
300 m
200 m
100 m
0
Boss Point Formation
Ward Point Member
Chignecto Bay Member
Base not exposed
coal
minor coal
162 *
161 *
160 *
159 *
158 *
Red lithofacies
Grey lithofacies
Trough cross-bedding
Ripple lamination
Plant debris
Petrified tree
Rooted horizon
Calcrete nodule
Siderite nodule
Intraformational mud or silt clast
Extrabasinal clast: rounded
Ostracod
159 * Spore sample locality
Concealed interval
f
m
c
CLAY
SILT
SAND
PEBBLE
COBBLE
GRAIN SIZE

Figure 58. Generalized stratigraphy of the Chignecto Bay and Ward Point members of the Boss Point Formation at Cape Maringouin, modified after Browne (1991).

Maringouin Peninsula and the Joggins and Springhill Mines formations in the Cumberland Group in Nova Scotia (Ryan et al. 1991; Ryan and Boehner 1994; Dolby 1999b).

Distribution and Thickness: The Boss Point Formation is geographically extensive, occurring as outcrop or in the subsurface over much of southeastern New Brunswick and northern Nova Scotia. It is best exposed in the type area around Chignecto Bay and Shepody Bay. In New Brunswick it outcrops in a '**Z**'-shaped tract lying on older Carboniferous and locally basement rocks from Parkindale in the west to Calhoun and Memramcook in the east, and from there south to Dorchester Cape and then southeast to British Settlement. In the southwestern part of the report area, the Boss Point is exposed in two main tracts: 1) on the northwest side of the Harvey–Hopewell Fault from Herring Cove in the southwest to Taylor Village in the northeast, and 2) on the west side of Chignecto Bay from Cape Enrage in the southwest to the southern Maringouin Peninsula in the northeast. A separate northeast-trending and southeast-dipping panel of Boss Point Formation occurs on Fort Cumberland Ridge near the New Brunswick–Nova Scotia border (Plate 5).

The Boss Point Formation as defined in this report is approximately 1075 m thick in the type section. This thickness estimate was determined by using detailed descriptions and measurements by Logan (1845), and was aided by field examination of the type section. It is identical to Bell's (1944) report of 3525 ft (1074.4 m). Ryan et al. (1991) and Ryan and Boehner (1994) estimate the type section to be 982 m thick and quote the overlying Joggins Formation thickness as 1433 m. Using Ryan and Boehner's measures, the combined thickness of the Boss Point and Joggins formations at their type sections is 2415 m. East of Dorchester Cape in the Sackville Subbasin near Evans (Plate 5), on the south limb of the Sackville Syncline, the Boss Point Formation has a calculated thickness of 2100 m to 2400 m. This measurement assumes that the section there is not complicated by unknown faults and that it dips north at 30° (2100 m) to 35° (2400 m). Therefore, the Boss Point in the western Sackville Subbasin has a thickness approximately equivalent to the combined thickness of the Boss Point and Joggins formations at Joggins. Worth noting here is the remarkable decrease in thickness of the Boss Point Formation from the southwestern to the northeastern end of the Sackville Subbasin. In Well 402 at the northeastern end of the basin near Port Elgin, the Boss Point has a true thickness of only 280 m (Fig. 55), meaning the formation has an eightfold decrease in thickness over a distance of 35 km.

In the Moncton Subbasin, the Boss Point Formation is thin, averaging less than 200 m where the base and top were intersected in boreholes. For example, in Well 319 just west of Turtle Creek (Fig. 55) the section is approximately 220 m thick; less than 6 km to the northwest in Well 146 (Fig. 13, 55) it thins to about 150 m.

Lower and Upper Boundaries: In the southeastern Moncton Subbasin and along the margin of the Caledonia Uplift northwest of the Harvey–Hopewell Fault, the Boss Point Formation lies disconformably to unconformably on the Hopewell Cape Formation of the Mabou Group and locally unconformably oversteps the Windsor, Sussex, and Horton groups to lie on crystalline basement (Plates 4, 6).

In the type area in Nova Scotia, the lower contact is placed at the base of dusky maroon, ripple-laminated siltstone and plant-bearing, fine-grained sandstone of the Chignecto Bay

Member, in accordance with Bell (1944) and Ryan and Boehner (1994). In contrast, most previous workers in New Brunswick have positioned the lower contact immediately below the first large-scale, trough cross-bedded, grey sand body (Norman 1941a; Gussow 1953; van de Poll 1973a; McLeod and Ruitenberg 1978; Browne 1991), which corresponds to the base of the Ward Point Member as defined herein. Elsewhere in New Brunswick, the base of the Boss Point Formation is characterized by quartz-pebble-rich conglomerates of the Breau Creek Member (Fig. 57).

The upper contact of the Boss Point Formation varies from conformable to disconformable. In the Cumberland Subbasin, the formation is overlain conformably by the Grande Anse Formation in the core of the Hard Ledges Syncline on the western side of Maringouin Peninsula (Fig. 6, inset; Plate 4). Elsewhere on the peninsula, the contact is either concealed or faulted against the Grande Anse Formation, such as at Johnson Mills and Green Creek. Directly along strike in Nova Scotia, the formation is conformably overlain by redbeds of the Little River Formation (Calder et al. 2005). In the Sackville and Moncton subbasins, the Boss Point Formation is disconformably overlain by the Salisbury Formation of the Pictou Group.

Depositional Environment: Extensive sedimentological and stratigraphical studies by Browne (1991) and Browne and Plint (1994) indicate that the Boss Point Formation was deposited within a large braided river system with associated open lacustrine, distributary channel, and deltaic environments. The reader is referred to the exhaustive Ph.D. thesis by Browne (1991) for details.

Age: As with other basal strata of the Cumberland Group in the Maritimes Basin, spore assemblages in the Chignecto Bay, Breau Creek, and Ward Point members of the Boss Point Formation contain key species such as *Kraeuselisporites echinatus, Ahrensisporties beeleyensis*, and *Spelaeotriletes arenaceus*. They also feature abundant corroded and reworked Windsor–Mabou arid association spores.

The precise age of these and other spore assemblages from the Cumberland Group became the focus of a heated debate in the late 1990s. Before that time, Barss (1968, 1971, 1977) and later Dolby (1994, 1995c, 1996a, 1996b, 1997a, 1997b) had assigned late Namurian to early Westphalian A ages to dozens of robust Boss Point spore assemblages from New Brunswick (Fig. 56). Even earlier, Bell (1944) proclaimed a Westphalian A (Langsettian) age for the Boss Point beds from megafloral collections. The late Namurian C–early Westphalian A age was challenged by Utting and Giles (1998) who, from collections in Nova Scotia and southwestern Newfoundland, argued for an older Namurian age for the basal Cumberland Port Hood Formation. Their evidence persuaded the present authors to have Dolby (1999b) reassess some earlier collections from New Brunswick, and accordingly Dolby's reassessed dates cited Kinderscoutian to early Namurian C (Yeadonian) ages for many of the samples (see St. Peter and Johnson 2009).

However, the work of Utting and Giles (1998) and Dolby (1999b) has since been superseded, and later palynological work on collections from the Boss Point Formation (Cumberland Group) in the Joggins section and from southeastern New Brunswick (Utting et al. 2005), as well as from megafloral collections (Utting and Wagner 2005), supports the long-held interpretation that the age of the type Boss Point Formation is late Namurian C to early

Westphalian A. Consequently, readers of the Dolby (1999b) report, and of the data from it reported in St. Peter and Johnson (2009), should be cautioned that the Kinderscoutian and Marsdenian ages assigned to the Boss Point assemblages are in all probability too old. A late Yeadonian to early Langsettian age for the formation is more likely (Fig. 56).

Relationship to Previous Stratigraphy: The Boss Point Formation as defined herein is synonymous with the formation as defined by Bell (1944). Logan (1845) made the first detailed lithological description and measurement of the section later designated by Bell (1914) as the type section of the Boss Point Formation. Although Bell (1914) originally included all of Logan's (1845) Division VI (predominantly grey sandstone) and Division VII (red sandstone and mudrocks) in the formation, he subsequently revised his definition to include Division VI and only the uppermost 86 m of Division VII (Bell 1944, p.15).

Norman (1941a) mapped the formation in the Chignecto Bay area in New Brunswick and extended its distribution into the Dorchester and Demoiselle Creek areas on the east and west sides of Petitcodiac River, respectively. On the basis of his lithological description and map of the Chignecto Bay area, it appears that Gussow (1953) followed Norman (1941a) and excluded the basal 86 m of redbeds considered part of the formation by Bell (1944). Detailed mapping and palynological work conducted during the present study support Bell's (1944) interpretation of what constitutes the Boss Point Formation in the Chignecto Bay area. The definition herein appears to be equivalent to that used by Ryan and Boehner (1994), according to contacts on their type section map. However, they reported a thickness of 982 m, 92 m less than the present authors' estimate of 1074 m, which includes additional strata below the formation as defined by Browne (1991).

Grey sandstone and conglomerate north of the Caledonia Uplift in the Moncton Subbasin were included in Zone 2 of the Petitcodiac Series by Wright (1922). He considered Zone 2 to be equivalent to the 'Millstone Grit' of Dawson (1868) and Ells (1885). Norman (1941a, 1941b) later used Bell's (1914) Boss Point Formation for Zone 2 of Wright (1922) south of Hillsborough, but left Zone 2 north of the Caledonia Uplift as undivided Petitcodiac Group. Gussow (1953) subsequently divided Norman's Petitcodiac Group into a lower unit of predominantly grey sandstone and conglomerate that he assigned to the Boss Point Formation and an upper, predominantly red unit that he assigned to the Salisbury Formation. Johnson (1995, 1996) originally concurred with Gussow's division. However, in the current report, the authors now include only the lower part of Gussow's Boss Point in the redefined Boss Point Formation north of the Caledonia Uplift (see ***Salisbury Formation***, later).

Chignecto Bay Member (Boss Point Formation)

Authors: New member name introduced herein.

Type Section: The type section (Fig. 46, 47, 59) is designated herein as coastal exposures on the east side of Maringouin Peninsula between 0.1 km and 0.4 km south of the mouth of Green Creek, Westmorland County (NTS 21H/16; Plate 5).

Reference Section: The member is also well exposed on the west side of Marys Cove (NST 21 H/10; Plate 6).

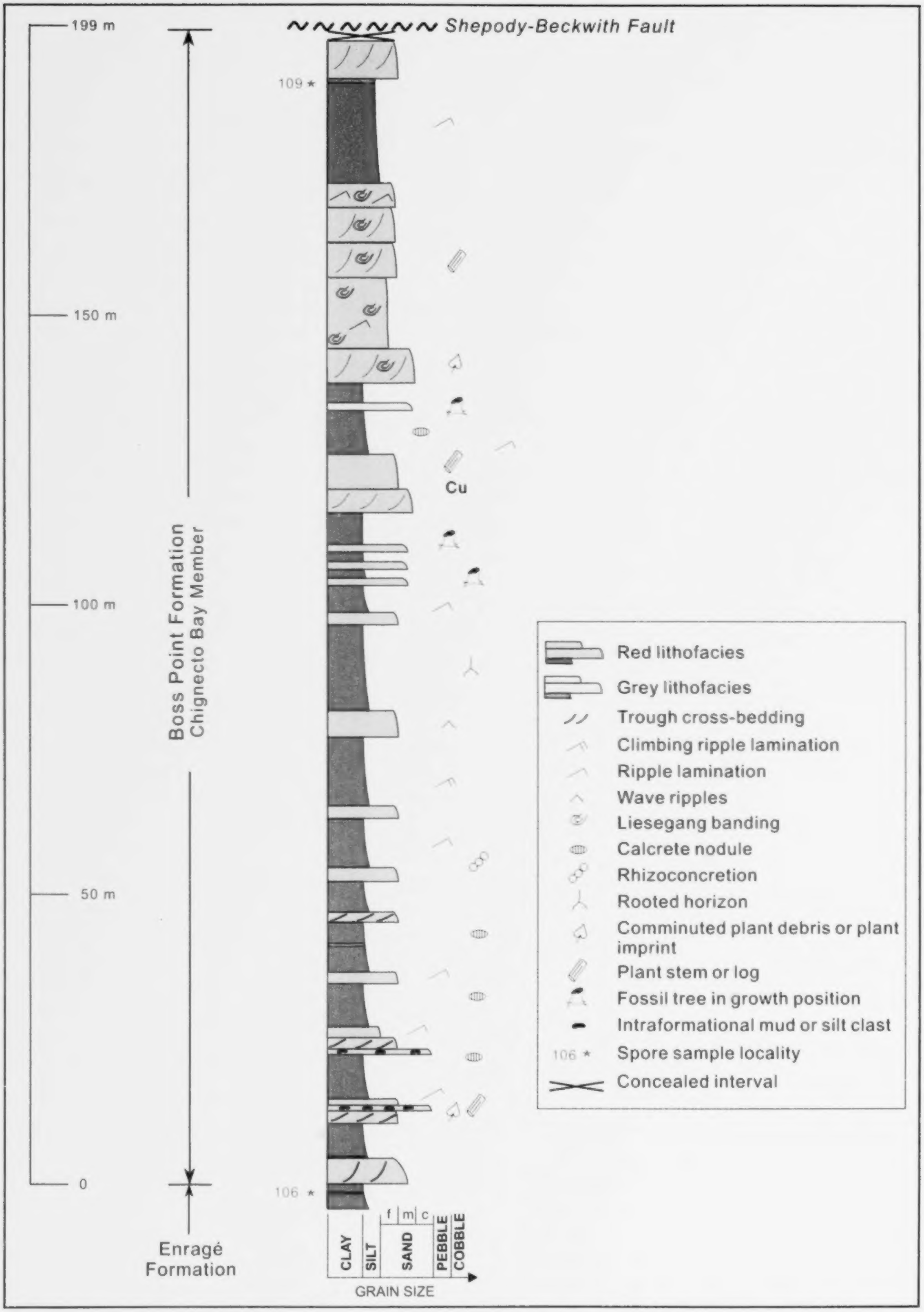

199 m
150 m
100 m
50 m
0
Shepody-Beckwith Fault
109 *
106 *
Cu
Boss Point Formation
Chignecto Bay Member
Enragé Formation
CLAY
SILT
SAND
f
m
c
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Trough cross-bedding
Climbing ripple lamination
Ripple lamination
Wave ripples
Liesegang banding
Calcrete nodule
Rhizoconcretion
Rooted horizon
Comminuted plant debris or plant imprint
Plant stem or log
Fossil tree in growth position
Intraformational mud or silt clast
106 * Spore sample locality
Concealed interval

Figure 59. Generalized stratigraphy of the type section for the Chignecto Bay Member, Boss Point Formation, near Green Creek on the east side of Maringouin Peninsula.

Definition and Description: The name 'Chignecto Bay Member' is proposed for the dusky maroon to reddish brown, ripple-laminated siltstone and fine-grained, arenaceous sandstone that consistently occupy the stratigraphic position immediately below the first major grey sandstone of the Boss Point Formation in the Cumberland Subbasin. Although these strata in Nova Scotia (e.g., Ryan and Boehner 1994) are not mapped as a separate member of the Boss Point Formation, the present authors feel it necessary in New Brunswick to designate them as separate and furthermore to exclude them from the Enragé Formation.

The Chignecto Bay Member comprises mainly dusky maroon to maroon-grey, ripple-laminated siltstone to fine-grained sandstone (Fig. 60a), and interbedded chocolate brown mudstone. The member contains subordinate maroon to maroon-grey, medium-grained, flat-bedded and small-scale trough cross-bedded, lithic and quartzose arenite. It lacks substantial channel sandstone units such as those that characterize the upper part of the Boss Point Formation. The member coarsens upward in the Cumberland Subbasin sections and comprises mainly sandstone in the upper part. In the type section, calcareous and manganiferous cannonball concretions and liesegang banding are common in the sandstone (Fig. 59). Calcrete nodules and rhizoconcretions are locally present in the siltstones and mudstones. A bed of small-pebble (1–2 cm), intraformational conglomerate with reddish brown pedogenic carbonate clasts occurs near the base of the formation in the type section. In contrast with the underlying Enragé Formation, the Chignecto Bay Member contains abundant evidence of plant life including in situ stems and imprints of *Calamites* and abundant *Stigmaria*. Several large *Sigillaria* trees (up to 1 m diameter) in their growth position occur in the sandstones along the shore at Green Creek (Fig. 60b). Malachite staining is locally associated with the plant remains.

In the area around Alma (Herring Cove, Dickson Brook, Cleveland Brook), the Chignecto Bay Member shows a general upward fining. A 12 m thick section exposed at the base of the member at Dickson Brook comprises medium to thick beds of reddish brown, well-rounded, granule to pebble conglomerate and maroon, fine- to medium-grained, trough cross-bedded and flaggy (flat-bedded) feldspathic arenite. The pebbles in the conglomerate are up to 4 cm in diameter and comprise competent lithotypes of vein quartz, quartzite, and rhyolite with only minor mafic volcanic rocks, schistose metasedimentary rocks, and epidotized arkose.

At Herring Cove, the Chignecto Bay section again shows a general upward fining. The lower part comprises graded beds of rounded quartz-pebble conglomerate, light red quartz-pebble grit, and medium- to coarse-grained feldspathic quartzose arenite. On the north side of a concealed interval, the member is finer and is formed of fining-upward sequences of channel lag conglomerate, massive to trough cross-bedded maroon sandstone, very fine-grained to fine-grained, ripple-laminated sandstone, and reddish brown mudstone. The channel-lag conglomerate beds have plant stems and locally abundant rounded ironstone pebbles up to 4 cm in diameter. X-ray fluorescence analyses of two pebbles give average values of Fe_2O_3 (89.65%), SiO_2 (5.32%), Al_2O_3 (2.20%), and MnO (0.41%). The mudstone intervals are thicker in the upper part of the section. The top of the member comprises a 10 m interval of mudstone that shows abundant evidence of soil development, including 1) greyish green reduced layers 2) varied development of micritic calcite nodules (but nowhere continuous limestone beds), 3) vertisol type slickensides, and 4) root traces. A 2 m thick interval of very fine-grained sandstone immediately below this upper mudstone also displays nodules of limestone and subvertical rhizoconcretions up to 60 cm long.

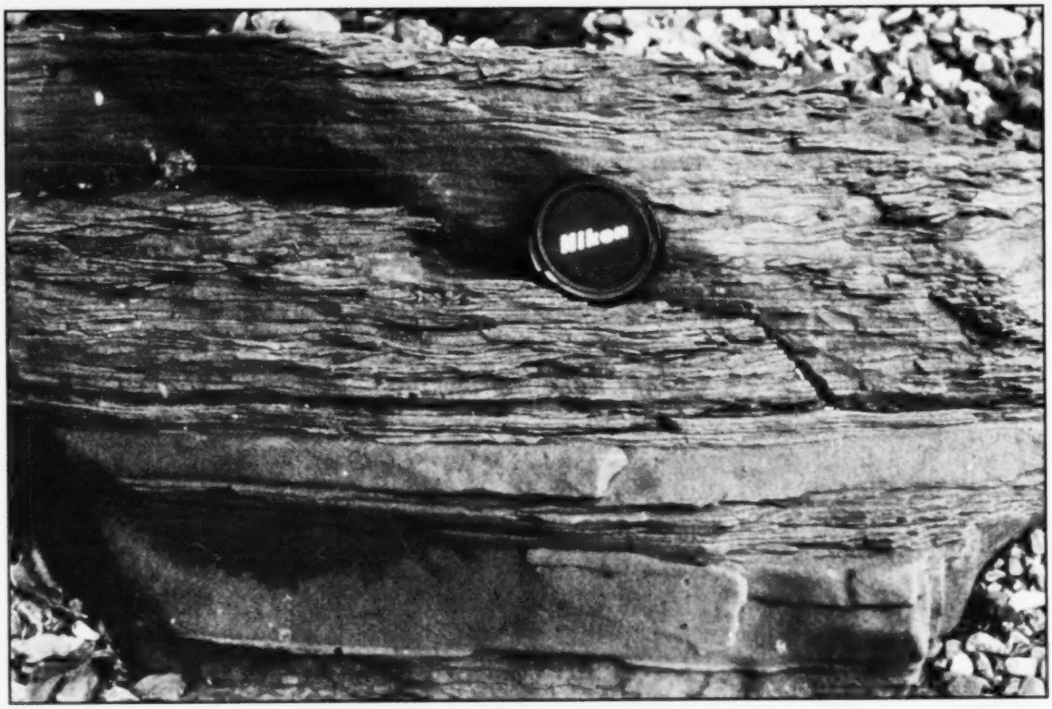


Figure 60a. Dusky maroon, ripple-laminated and flat-bedded sandstone of the Chignecto Bay Member, Boss Point Formation, at Herring Cove in Fundy National Park.

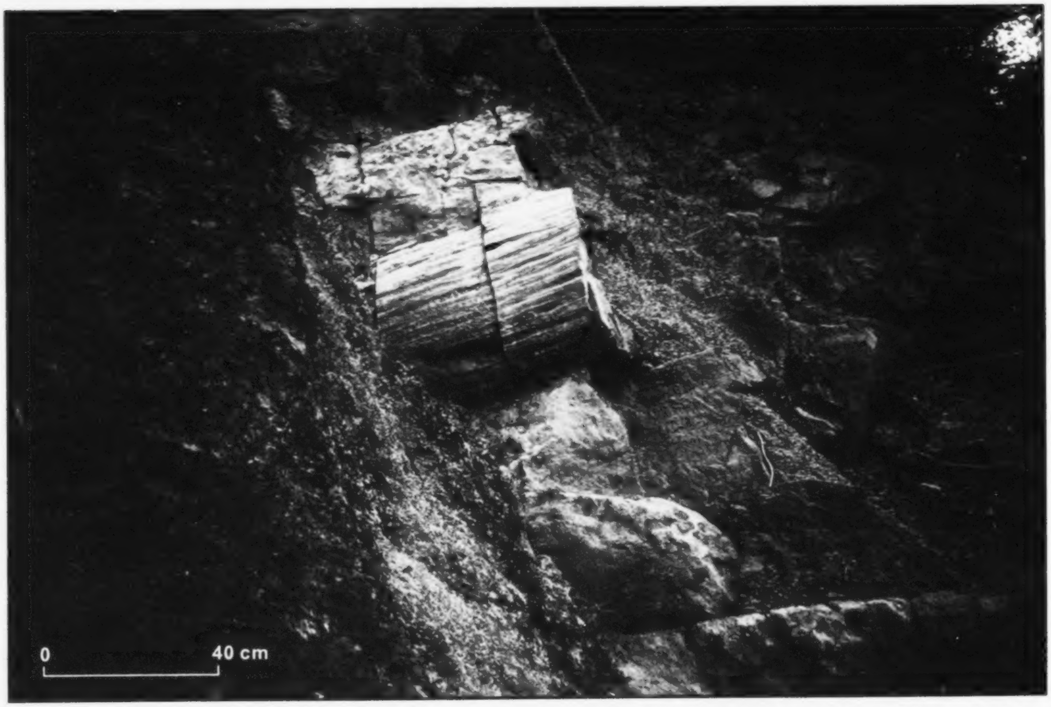


Figure 60b. In situ fossil of lycopsid tree in vertically dipping beds of the Chignecto Bay Member, Boss Point Formation, at the type section for the member at Green Creek on the west side of Cumberland Basin.

Distribution and Thickness: The Chignecto Bay Member is geographically restricted. In the Cumberland Subbasin, it occurs on both limbs of the Maringouin Anticline (Fig. 6, inset; Plates 5, 6) on Maringouin Peninsula and in the area from Rocher Bay northeast to Marys Cove. It also occurs on the south flank of the Caledonia Uplift, north of the Harvey–Hopewell Fault, from Alma northeast to Demoiselle Creek, and in Boss Cove, Nova Scotia, on the east side of Cumberland Basin (Fig. 6). The member attains an estimated maximum known thickness of 200 m in the type section, but the upper contact there is faulted (Fig. 59). Directly along strike on the west shore of Maringouin Peninsula, it is only 95 m thick where it is overlain by multistoried channel sandstone of the Ward Point Member on the north limb of the Maringouin Anticline. A thickness of approximately 120 m was measured on the south limb of the anticline near Cape Maringouin, where it is also succeeded by the Ward Point Member (Fig. 58).

In the area around Alma (Dickson Brook, Cleveland Brook), the member varies from 40 m to 60 m thick and from there thins to a zero edge north of Germantown. In the tract between Riverside–Albert and Demoiselle Creek, it is thickest at Sawmill Creek where about 45 m are exposed (Plate 4).

Lower and Upper Boundaries: The lower contact of the Chignecto Bay Member in the Cumberland Subbasin is positioned at the base of the first beds of drab maroon to grey or reddish brown, ripple-laminated, fine-grained sandstone and siltstone or at the base of small-scale, trough cross-bedded, non-arkosic sandstone. A section across this stratigraphic interval is exposed in the Cumberland Subbasin south of Green Creek on the east side of Maringouin Peninsula (Fig. 49). The section comprises north-younging, vertical to overturned beds of variegated, brick red siltstone and arkosic grits of the uppermost Mabou Group (Enragé Formation) overlain by similarly oriented thin-bedded, dusky maroon, plant-bearing sandstones and interbedded maroon and reddish brown, ripple-bedded siltstone of the Chignecto Bay Member (Fig. 59). The concordant nature of the contact suggests that in the axial part of the Cumberland Subbasin this boundary is likely disconformable.

On the south flank of the Caledonia Uplift, the base of the Chignecto Bay Member is located at the base of the first bed of rounded competent pebble conglomerate that lies on immature polymictic conglomerates or associated lithic sandstones and pedogenic mudstones of the Hopewell Cape Formation. As discussed above, this contact is considered to be unconformable to disconformable. (The unconformity at Cleveland Brook is described earlier under ***Hopewell Cape Formation***.) The lower contact at Cape Maringouin is interpreted to lie in a concealed zone in the small unnamed cove north of the cape (Fig. 37). Following the detailed lithological descriptions of Logan (1845), the present authors likewise suggest that the position of the lower boundary lies in the concealed zone at the north end of Boss Cove along strike in Nova Scotia.

The contact with the overlying Ward Point Member is exposed at Herring Cove and Cape Maringouin and is placed at the base of the first major interval of buff-weathering, grey, large-scale, trough cross-bedded, channel sandstone. The upper contact is faulted in the type section near Green Creek where vertical to overturned strata of the Chignecto Bay Member are truncated by the Shepody–Beckwith Fault (Fig. 59). Along formational strike to the southwest, on the opposite side of Maringouin Peninsula near Johnson Mills, the upper contact of the Chignecto Bay Member is marked by a small fault, but superpositional relationships are preserved. Slickensides on the fault indicate that the dominant movement on the fault was strike slip.

Depositional Environment: Lycopod trunks preserved in growth position in this member indicate very rapid sedimentation rates. Calder (2000) and Davies and Gibling (2003) describe the processes by which the in situ fossil forests of Joggins were entombed as recurrent overtopping of distributary channels onto the interchannel areas in a high-subsidence basinal setting. The present authors envision a similar depositional process for the Chignecto Bay Member.

Age: A spore sample (spore locality 109 on Plate 5) from the upper part of the type section at Green Creek (Fig. 59) contained a too meagre assemblage to assign a precise age (Dolby 1997b). A sample from beds near the mouth of Dickson Brook (spore locality 110 on Plate 6) also yielded a poor assemblage that allowed only a non-specific Namurian age (Dolby 1997a). A third sample collected from the upper part of the member at Herring Cove (spore locality 111 on Plate 6) yielded a similarly lean assemblage containing saccate pollen and *Florinites visendus,* which are typical of basal Boss Point rocks and imply a late Namurian or early Westphalian A age (Dolby 1996a).

Relationship to Previous Stratigraphy: Prior to this study, rocks of the Chignecto Bay Member were included in the Enragé or Claremont formations (Norman 1941a; Flaherty and Norman 1941; Gussow 1953; Browne 1991). On his detailed stratigraphic logs for Cape Maringouin and Boss Point, Browne (1991) assigned these rocks to the Claremont Formation, but on his Map 2, he showed the Chignecto Bay type section as part of the Boss Point Formation. The Chignecto Bay Member is equivalent to van de Poll's (1994, p. 196) Enragé Formation at Herring Cove, Owls Head, and Alma. At Cape Maringouin and along strike in Boss Cove, Nova Scotia, these beds were included in the Enragé Formation by van de Poll (1973a). In Nova Scotia, Bell (1944) and Ryan and Boehner (1994) assigned these rocks to the Boss Point Formation. In the Joggins section on the east shore of Chignecto Bay, the member is equivalent to the uppermost 86 m of Logan's (1845) Division VII and lowermost 85 m of Division VI.

Ward Point Member (Boss Point Formation)

Authors: New member name introduced herein.

Type Section: The type section is designated herein as the coastal exposures that extend from Ward Point on the southeastern tip of Maringouin Peninsula westward through Slacks Cove to the Lower Rockport area (Fig. 37) in Westmorland County (NTS 21 H/10; Plate 6). Figure 58 offers a generalized stratigraphic log for the section exposed at Cape Maringouin, directly along strike of the type section.

Definition and Description: The name 'Ward Point Member' is proposed herein for dominantly grey, multistoried, large-scale, trough cross-bedded sandstone and pebbly sandstone, fine-grained sandstone, grey siltstone, and silty mudstone that characterize the Boss Point Formation in the type section (Fig. 61a, 61b). The grey mudstones locally contain siderite nodules and siderite-rich beds. Ostracod-bearing carbonaceous limestone,

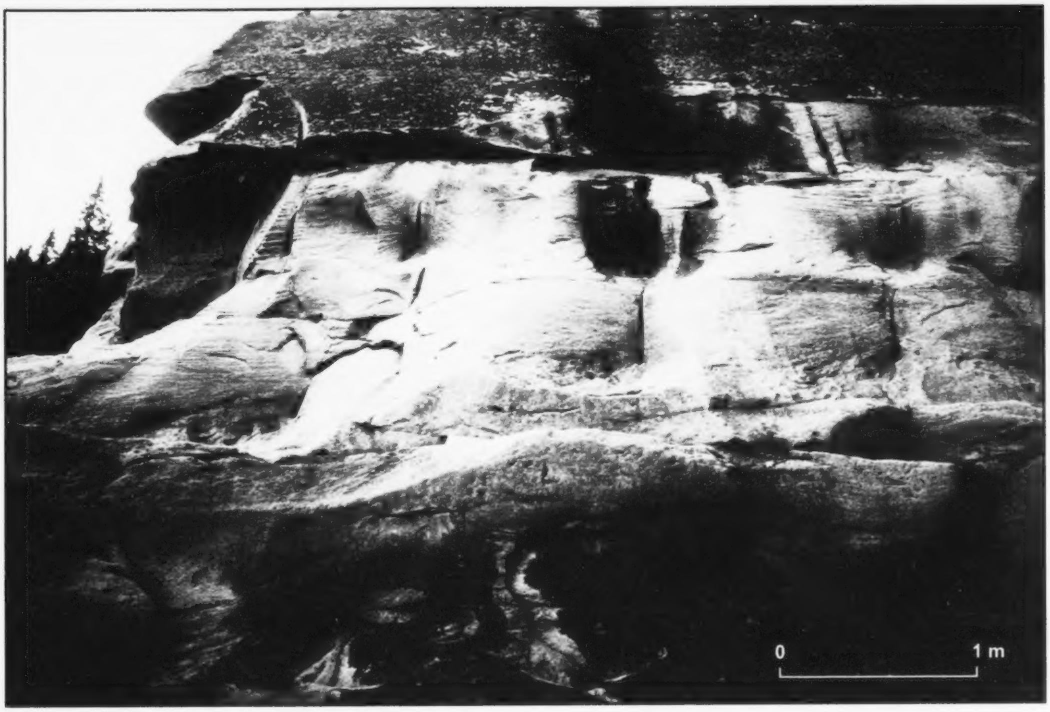


Figure 61a. Multistoried sandstone beds of the Ward Point Member, Boss Point Formation, at Slacks Cove on the southern tip of Maringouin Peninsula.

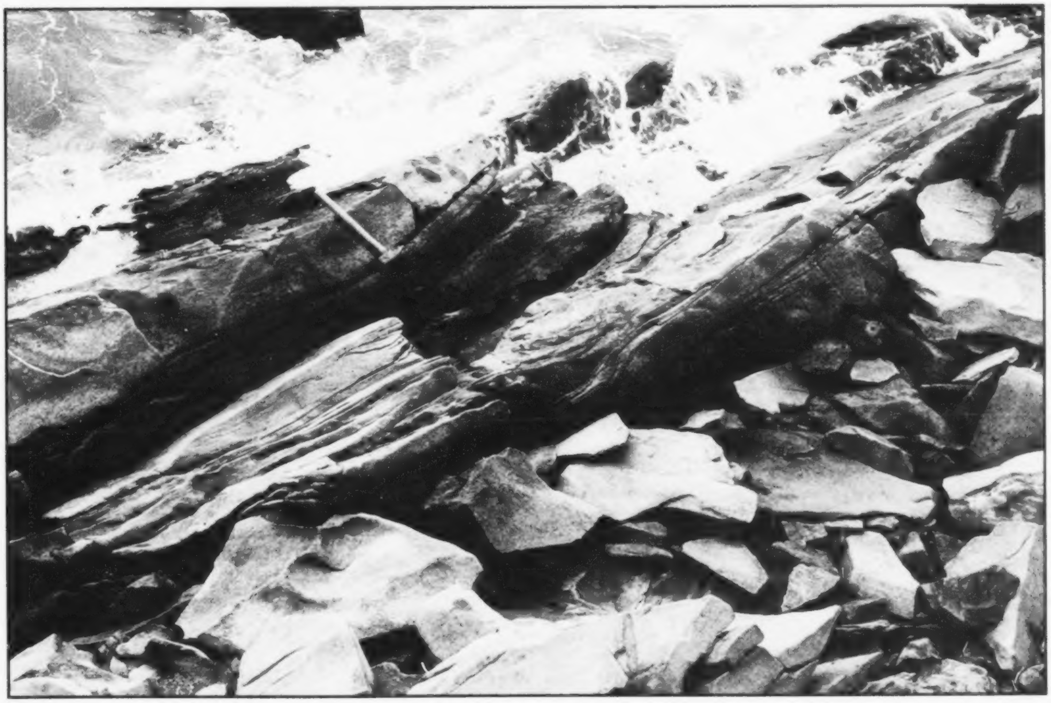


Figure 61b. Small-scale trough cross-bedding in grey sandstones of the Ward Point Member, Boss Point Formation, at Slacks Cove on the southern tip of Maringouin Peninsula.

carbonaceous shale, and thin coal seams of lacustrine origin occur locally (Browne 1991). Lacustrine strata are unknown in the other members of the Boss Point Formation in New Brunswick.

Dusky maroon, reddish brown and minor grey, ripple-laminated, very fine-grained to fine-grained sandstone, siltstone and massive to laminated mudstone are interbedded with grey channel sand units in the lower part of the member. Trough cross-bedded sandstones are typically grey, greyish green, or olive green, and range widely in composition from quartzose arenite (sublitharenites and subarkoses) to litharenites and arkose (Fig. 62). Channel-lag conglomerate with intraclasts of grey silty mudstone, less commonly limestone or siderite nodules, and pebbly sandstone containing rounded quartz and grey mudstone clasts occur near the base of some trough cross-bedded sand units. Coalified plant material is locally very abundant, and carbonized logs are found along the coast at Slacks Cove and Ward Point on Cape Maringouin. Calcareous and manganiferous cannonball concretions are also a common feature within the sandstones.

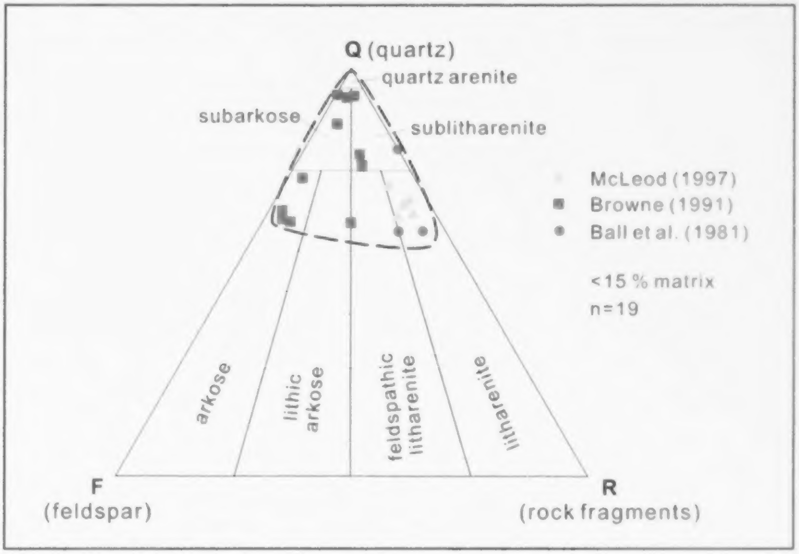


Figure 62. Ternary diagram showing sandstone composition of the Boss Point Formation. Raw data of McLeod (1997) recalculated to 100%. QFR ternary base diagram after Folk (1974).

Distribution and Thickness: The member is geographically restricted to the Cumberland Subbasin and thus lies south of the Harvey–Hopewell and Shepody–Beckwith faults (Plates 4–6). On Maringouin Peninsula, the member is exposed on the north and south limbs of the Maringouin Anticline (Fig. 6, inset). On the west side of Chignecto Bay, it is exposed in a fault-complicated syncline on the footwall side of the Lockhart Lake Fault and in a steeply dipping tract that forms most of the coastal exposures from Cape Enrage to Marys Point and from there eastward to the type area on Maringouin Peninsula. The Ward Point Member and underlying Chignecto Bay Member comprise the type section of the Boss Point Formation at Boss Point, Nova Scotia (Fig. 6).

On Maringouin Peninsula, the exposed part of the section of the Ward Point Member is approximately 500 m thick at Cape Maringouin, and a similar thickness is estimated for the type section to the east at Ward Point (Fig. 37, 58). The uppermost beds in the type area lie beneath the waters of Chignecto Bay. The base and top of the Ward Point Member are exposed directly along strike at Boss Point, Nova Scotia, where the member attains a thickness in the order of 950 m. A similar thickness of 950 m was calculated for the member on the opposite (north) limb of the Maringouin Anticline near Johnson Mills.

Lower and Upper Boundaries: The lower contact with the Chignecto Bay Member is gradational and is defined by the first occurrence in ascending the section of grey, large-scale, trough cross-bedded arenite. This contact is the boundary between the Enragé and Boss Point formations of Norman (1941a) and Gussow (1953), which they considered to be conformable (Fig. 45). The upper contact is exposed in the Hard Ledges Syncline near Johnson Mills (Plate 4), where the member appears to pass gradationally into redbeds of the Grande Anse Formation. In the Boss Point type section in Nova Scotia, rocks considered correlative with the Ward Point Member are conformably overlain by redbeds of the Little River Formation, the latter of which are tentatively correlated with the Grande Anse Formation of New Brunswick (Calder et al. 2005).

Depositional Environment: An exhaustive sedimentological study of the Boss Point Formation was undertaken by Browne (1991) and summarized in Browne and Plint (1994). He and they demonstrate that the Ward Point Member comprises two alternating facies associations consisting of sandy braidplain and muddy lacustrine environments.

Age: A total of 24 spore-bearing samples are recorded from the Ward Point Member in New Brunswick (Table 3). The samples from the type area (localities 158–165 and CC on Fig. 37) are characterized by abundant monosaccate gymnosperm pollen and an absence of the Windsor–Mabou arid association spores. The samples contain what appear to be in situ species such as *Ibrahimispores* spp., which die out in the early or middle Namurian in Europe. However, the samples also contain *Lycospora orbicula, Florinites cf. florinii, Lophotriletes microsaetosus,* and *Granulatisporites cf. microgranifer*, which are more characteristic of the Westphalian (Dolby 1996b). Carr (1968) reported a Westphalian B miospore age for a coal seam in this member at Slacks Cove on Maringouin Peninsula (spore locality CC on Plate 6). However, a sample collected from the same seam was assigned a late Namurian C to early Westphalian A age by Dolby (1996b).

At present, it is not possible to define the Namurian–Westphalian boundary in Europe. The problem is further complicated in Atlantic Canada by the absence of stratigraphically diagnostic spores recorded in Europe (Utting et al. 2005). Nevertheless, the assemblages are sufficiently diverse to assign a late Namurian C (late Yeadonian) to early Westphalian A (early Langsettian) age (Fig. 56) to the Boss Point Formation at the Joggins type section and by extension to the Ward Point Member in New Brunswick (Dolby 1996a, 1996b, 1997a).

Relationship to Previous Stratigraphy: The Ward Point Member is the most characteristic lithology of the Boss Point Formation and hence was included in the formation by all previous workers (e.g., Norman 1941a; Gussow 1953; van de Poll 1970, 1973a; Browne 1991). In the Joggins section in Nova Scotia, all but the lowermost 85 m of Logan's (1845) Division VI are equivalent to the Ward Point Member.

Breau Creek Member (Boss Point Formation)

Authors: New member name introduced herein.

Type Section: The type section is designated herein as exposures along Breau Creek and in an adjacent quarry just south of the creek, approximately 0.5 km east of a woods road that leads north from the community of Woodhurst, Westmorland County (NTS 21 H/16; Plate 5).

Definition and Description: The name 'Breau Creek Member' is used herein to describe the pebble conglomerate-rich unit that defines the base of the Boss Point Formation in the Moncton and Sackville subbasins and on the Westmorland Uplift. The member is composed mainly of buff-weathering, grey to olive green, fine- to medium-grained, pebbly, lithic, and quartzose arenite; and trough and planar cross-bedded, massive granule to pebble conglomerate (Fig. 63a, 63b). Minor fine-grained units include grey and reddish brown, parallel- and ripple-laminated, very fine-grained to fine-grained sandstone, siltstone, and mudstone. The pebble conglomerates are locally very abundant and form a significant part of the total member thickness.

Although Browne (1991) does not separate the Boss Point Formation into members, he reports that the conglomeratic facies are more prevalent near basin margins and presumed active Carboniferous faults. The current report supports his observations. An example of this lithofacies occurs north of the Dorchester Fault in the former Acton quarry near Breau Creek (Fig. 63a) where approximately 8 m of massive and trough cross-bedded orthoconglomerates are exposed. Pebbles are typically less than 5 cm in diameter (but can reach up to 20 cm), are subrounded to well rounded, and are composed chiefly of competent lithologies such as quartz and felsic volcanic rocks. Detailed pebble lithology studies of Boss Point conglomerates by van de Poll (1970) and Browne (1991) suggest that about 55% to 70% of clasts are quartz.

Distribution and Thickness: The member is spatially associated with the margins of exposed or shallowly buried basement blocks such as the Caledonia, Westmorland, and Hastings uplifts (Fig. 6). It flanks the southeastern margin of the Caledonia Uplift north of the Harvey–Hopewell Fault from Alma northeast to Demoiselle Creek. On the north side of the Caledonia Uplift, Breau Creek beds form a continuous tract from Parkindale northeast to Stoney Creek. The belt continues northeast to Calhoun where the beds overstep all older Carboniferous formations and lie on exposed basement of the Westmorland Uplift. From Calhoun, the member swings southeasterly and then southerly to the type section at Breau Creek. The beds step across the Dorchester Fault into the Sackville Subbasin, where they strike to the southwest and lie on the north limb of the Sackville Syncline. A well-exposed section occurs at Dorchester Cape on the south (north-dipping) limb of the Sackville Syncline (Plate 5). On the north flank of the buried Hastings Uplift (Fig. 6) between Westcock and Upper Point de Bute, a separate and largely fault-bounded block of Breau Creek and Cole Point strata lie southeast of the Tantramar Fault and north of the Wood Creek Fault (Plate 5).

On the southeastern flank of the Caledonia Uplift north of Germantown, a minimum thickness of the Breau Creek Member is calculated from an approximate true dip of 20° to be 600 m (Plate 6). East of Sackville on the southern end of Fort Cumberland Ridge, an identical

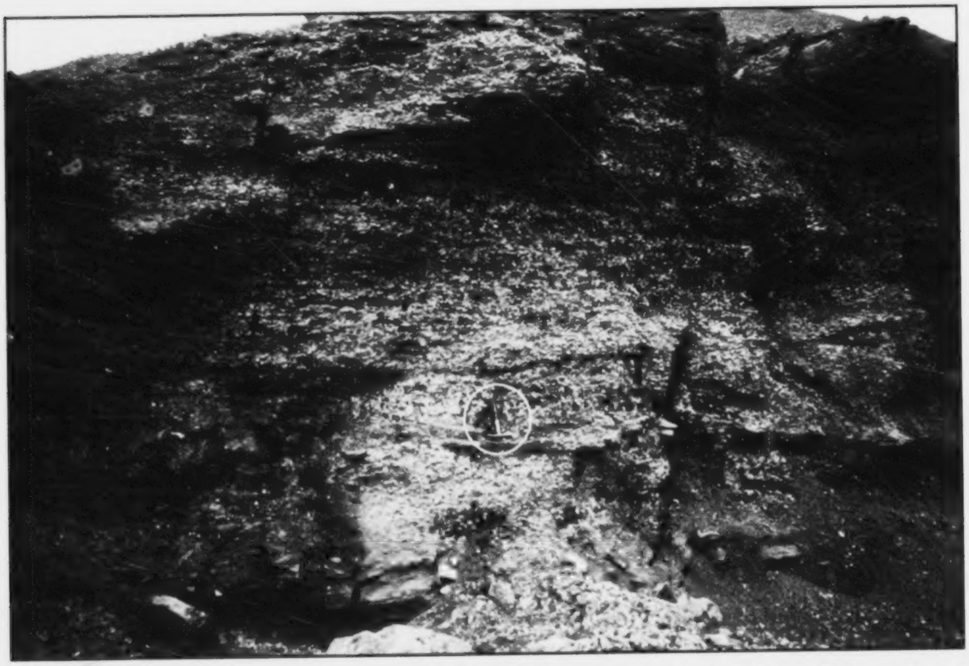


Figure 63a. Thick, trough cross-bedded pebble conglomerate of the Breau Creek Member, Boss Point Formation, at the former Acton quarry near Breau Creek. Hammer for scale (circled).

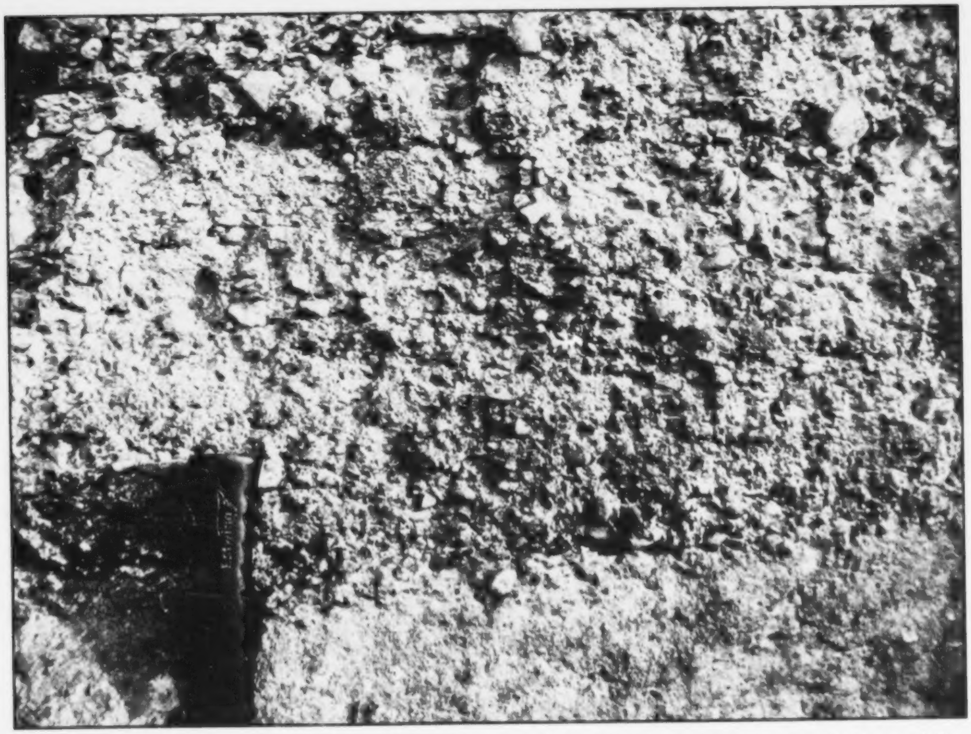


Figure 63b. Quartz-pebble conglomerate overlying grey quartzose sandstone of the Breau Creek Member, Boss Point Formation, at Edgetts Landing south of Hillsborough.

thickness of about 600 m is calculated from an average dip of 25° (Plate 5). The unbroken section at Dorchester Cape exposes 360 m of strata (Fig. 57; Plate 4). On the north side of the Caledonia Uplift from Parkindale to Calhoun, the member is considerably thinner, ranging from 25 m to 90 m (Fig. 55).

Lower and Upper Boundaries: The member unconformably overlies older Carboniferous rocks and locally basement (e.g., at Calhoun on Plate 3) and conformably overlies the Chignecto Bay Member northwest of the Harvey–Hopewell Fault. The upper contact is considered to be conformable. It is positioned at the top of the highest conglomerate bed and/or at the base of a thick, finer grained interval of sandstone or mudstone that characterizes the overlying Cole Point Member (Fig. 57).

Depositional Environment: Browne (1991) interprets conglomerate lithofacies in the Boss Point Formation to be coarse-bedload, braided channel deposits that were locally sourced. The high compositional maturity and degree of roundness of the clasts were previously used by van de Poll (1970) to suggest that the conglomerates were distally sourced. Browne (1991) argued for a local source because of the apparent lack of conglomerate away from the local highlands. The conglomerate is spatially associated with basin margins and is rare to absent in the axial part of the Cumberland Subbasin (Browne 1991; Ryan and Boehner 1994; this report). This latter point may be the most conclusive evidence in support of a local source. The spatial association between the conglomerate and the basin margins is likely a function of the proximity to paleofault scarps. The compositional maturity of sandstone depends more on energy of the fluvial system than on transport distance. Hence, higher gradient, gravel-carrying streams can produce compositionally mature sandstone over comparatively short distances (Pettijohn 1975; Browne 1991).

Age: Spore assemblages from the Breau Creek beds are assigned a late Namurian to early Westphalian A (early Langsettian) age (Fig. 56) by Barss (1968, 1971, 1977) and Dolby (1995c, 1996a, 1996b). A later examination of additional samples (Dolby 1999b) gives older ages of Namurian (Kinderscoutian to Marsdenian); see the earlier discussion of this discrepancy under ***Boss Point Formation***. More recent work on palynological collections (Utting et al. 2005) and megafloral collections (Utting and Wagner 2005) from the Boss Point type section at Joggins supports a late Namurian to early Westphalian A age for the Breau Creek Member.

Relationship to Previous Stratigraphy: Strata of the Breau Creek Member comprise the lower part of the Boss Point Formation as mapped by Norman (1941a) and Gussow (1953) in the Moncton and Sackville subbasins. The member is also equivalent to the lower part of Norman's (1941a, 1941b) undivided Petitcodiac Group in the Parkindale, Stoney Creek, and Moncton areas.

Cole Point Member (Boss Point Formation)

Authors: New member name introduced herein.

Type Section: The type section (Fig. 57) is designated herein as coastal exposures on the east side of Shepody Bay near Cole Point at the northern end of Dorchester Cape, Westmorland County (NTS H/15; Plate 4).

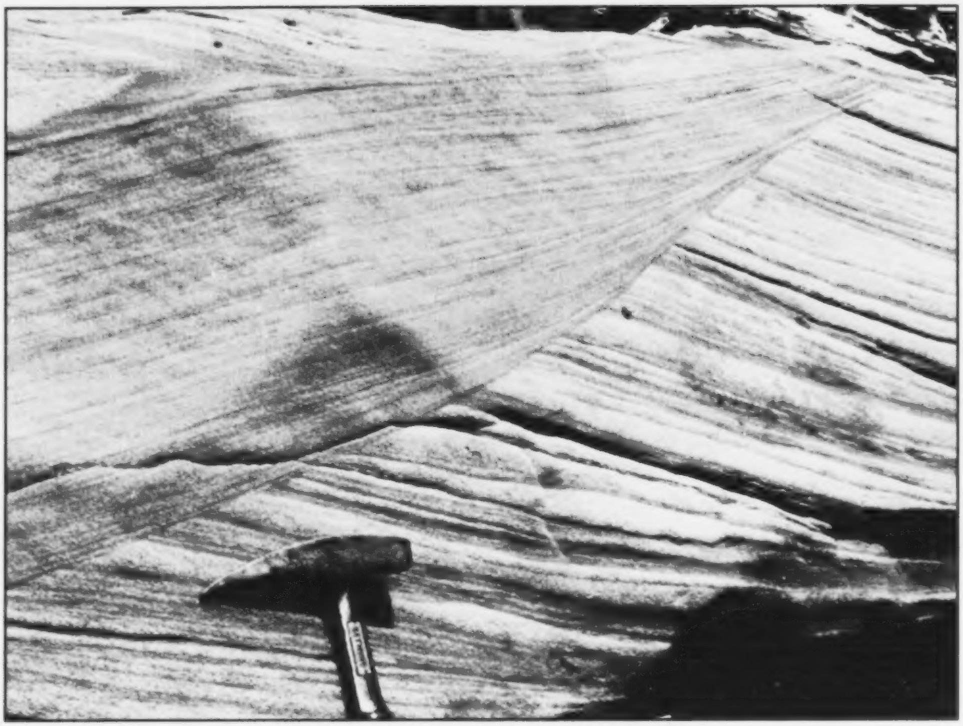


Figure 64. Trough cross-bedding in coarse-grained quartzose arenite of the Cole Point Member, Boss Point Formation, at the northern end of Dorchester Cape.

Definition and Description: The Cole Point Member as defined herein consists of grey to pinkish grey, buff, and minor red brown, fine- to coarse-grained and pebbly, feldspathic quartzose arenite, quartz arenite, and minor conglomerate (Fig. 64). The sandstones and pebbly sandstone typically form thick, multistoried units alternating with thinner units of bluish grey, maroon, or reddish brown, silty mudstone, siltstone and very fine-grained, parallel- and ripple-laminated sandstone. Coalified plants and pyrite nodules are locally abundant. Large carbonized and permineralized logs occur locally in the sandstones.

A fairly extensive interval of quartzose arenite and pebbly arenite with lenses of mottled buff and smoky grey, vitreous quartz arenite occurs near the top of the member overlying the shallowly buried Westmorland Uplift along Memramcook and Tantramar rivers. This highly indurated, silica-rich interval typically exhibits undulating nodular bedding surfaces that resemble silica-cemented paleosols.

The siliceous sandstone contains abundant detrital pyrite that has been locally remobilized into clots and veinlets. Johnson and McLeod (1998) investigated it for paleoplacer gold potential.

Distribution and Thickness: The Cole Point Member occurs in a northeast-trending belt extending from Little River (Plate 4) to Lower Coverdale (Plate 3), continuing east along Memramcook River, then south to Cookville (Plate 2). It continues into the Sackville Subbasin where it is exposed on both limbs of the Sackville Syncline and in a separate, fault-bounded tract on Fort Cumberland Ridge in the Sackville area (Plate 5).

Within the Moncton Subbasin, on the south flank of the buried Westmorland Uplift in Well 319 just west of Turtle Creek, the Cole Point Member is about 170 m thick (Fig. 55). The thickness decreases abruptly to the north, becoming only 35 m near the crest of the Westmorland Uplift in Well 406 at Lower Coverdale. Conversely, the thickness seems to increase significantly from the north limb to the south limb of the Sackville Syncline — that is, from the Westmorland Uplift south into the Sackville Subbasin. For example, on the north side of the Dorchester Fault (Plates 2, 5), shallow to subhorizontal dips indicate a section perhaps not much more than 100 m thick (Fig. 55; also see Well 397 (16 km south of Barachois) on Plate 2). On the north side of the Sackville Subbasin in the area of Beech Hill Provincial Park (Plate 5), the preserved section dips at approximately 10° and is about 800 m thick. In marked contrast, the section is about 1800 m thick at Evans on the south limb of the Sackville Syncline where the dip is about 35°. Approximately 450 m are exposed at the type section (Fig. 57), but the upper part of the member is omitted by a splay of the Harvey–Hopewell Fault (Plate 4).

Lower and Upper Boundaries: The Cole Point Member overlies the Breau Creek Member with apparent conformity. The basal contact is placed where thick, multistoried sandstones become dominant in ascending the type section at Dorchester Cape (Fig. 57).

The upper contact with the Salisbury Formation is disconformable to unconformable (see ***Salisbury Formation***, later). On Little River in the western part of the report area (Plate 4), the contact between the Cole Point Member and the Salisbury Formation is difficult to recognize on lithological evidence. The Salisbury Formation is characterized by a thick basal unit comprising stacked channel sandstones that are virtually identical to those in the underlying Cole Point Member. It is thus extremely difficult to place the contact using lithological criteria alone. The reddish brown mudstone intraclasts in the sandstones and minor interbeds of reddish brown, fine-grained sandstone and mudstone are the only lithological features that characterize the lower Salisbury Formation and serve to distinguish it from the underlying Cole Point Member on Little River.

Depositional Environment: Browne (1991, p. 332) suggests that the preponderance of stacked sandstone sequences and rarity of mudrocks in the Boss Point Formation indicate deposition in a very wide channel belt–floodplain during active tectonic subsidence.

Lateral Facies Relationships: The Cole Point Member in the Moncton and Sackville subbasins is wholly or partly time-equivalent with the Ward Point Member in the Cumberland Subbasin but is distinguished lithologically from the Ward Point by a lack of lacustrine deposits. The Cole Point Member and Grande Anse Formation are the youngest units of the Cumberland Group exposed in New Brunswick. As discussed below under ***Age***, the Cole Point Member may in part be time-equivalent to units overlying the Boss Point Formation in the classic Joggins section (Calder et al. 2005; Utting et al. 2005).

Age: The Cole Point Member was assigned an age of middle Langsettian to early Duckmantian by Dolby (1999b), although the strata are likely older (see below). Dolby (1982, 1995c, 1999a, 1999b) noted that the member contains abundant and diverse *Florinites* microflora along with forms such as *Cananoropollis mehtae*, *Wilsonites vesicatus*, and striate bisaccates. The presence of *Vestispora tortuosa* in three separate outcrop samples collected near the top of the Cole Point Member in the Sackville Subbasin (two at locality BT and one at locality BV on Plate 5) are of particular interest, as *V. tortuosa* makes its first appearance at the base of the Springhill Mines Formation — well above the Boss Point Formation in the Joggins section.

In contrast with the other members of the Boss Point Formation, the Cole Point Member contains abundant and diverse *Florinites* microflora and *Wilsonites* spp. Early Langsettian or older taxa such as *Spelaeotriletes arenaceus* have not been observed in the Cole Point Member. The member also contains striate bisaccate pollen. They have not been recorded in other members of the Boss Point Formation, although striate pollen were recently identified in rocks as old as the *G. listeri* Goniatite Band (Westphalian A; Fig. 56) in Europe (G. Dolby, pers. comm. to SCJ, 1999).

Dolby suggests that the presence of striate pollen in the Boss Point Formation outside the type area may have been controlled by and reflect an environmental difference between intermontane coal basins and marginal coal swamps. Note that the key pollen species used to constrain the age of the Cumberland Group are selected according to a European spore zonation scheme. Thus, if those key species emerged earlier in the intermontane coal basins of Carboniferous Maritimes Canada than in the marginal marine coal swamps of western Europe, the strata in the upper part of the Boss Point Formation (e.g., Cole Point Member) may be older than what the European zonation would predict.

Spore assemblages in the Cole Point Member are most similar to those in the Grande Anse Formation and other post-Boss Point, Langsettian units of the Cumberland Group in the Joggins section (Calder et al. 2005; Utting et al., in press). This suggests a similar Langsettian age for the Cole Point Member.

Relationship to Previous Stratigraphy: The strata assigned herein to the Cole Point Member on the northwest side of the Caledonia Uplift and in the Moncton area were included in the undivided Petitcodiac Group of Norman (1941a, 1941b). Gussow (1953) placed the Cole Point beds in the upper part of his Boss Point Formation in most places, except from Calhoun (Plate 3) southeast to Aboushagan Road (Plate 5), where he assigned the Cole Point strata to his Salisbury Formation.

Grande Anse Formation

Author: Norman (1941a).

Type Section: Norman (1941a) named the formation after Grande Anse, a large cove on the western side of Maringouin Peninsula (Fig. 65). The type section (Fig. 66, 67) is therefore designated herein as the low coastal cliffs and outcrops in the intertidal zone along the east side of Shepody Bay, extending from Grande Anse at the mouth of Johnson Creek (HTS 21 H/16; Plate 5) south for 3.3 km (NTS 21 H/15; Plate 4).

Reference Section: An equally well-exposed but less accessible section lies on the east side of Maringouin Peninsula, reaching from Black Point (Fig. 65) northward to, but excluding, Allen Creek (NTS 21 H/16; Plate 5). The rocks lie directly along strike and eastward of the type section.

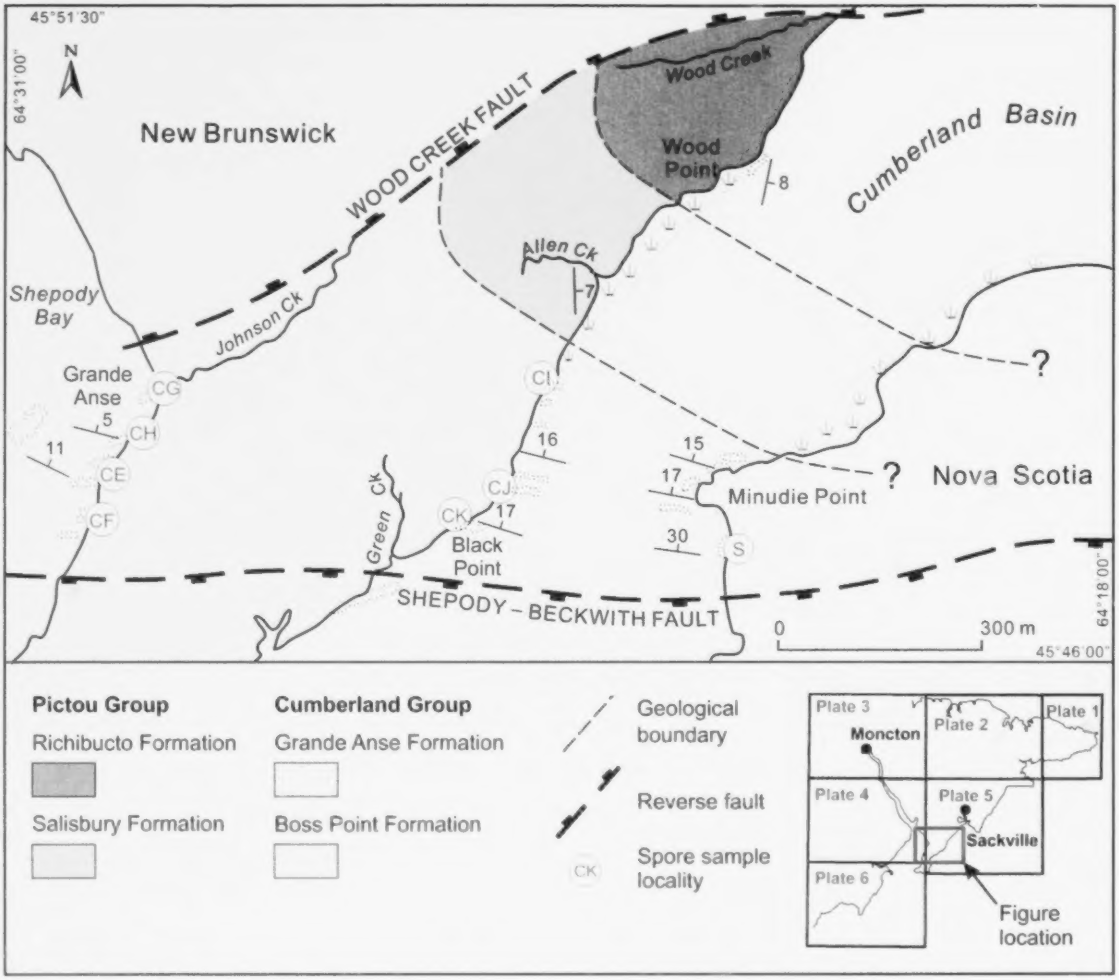

45°51'30"
64°31'00"
N
New Brunswick
WOOD CREEK FAULT
Wood Creek
Wood Point
Cumberland Basin
8
Allen Ck
7
Shepody Bay
Johnson Ck
Grande Anse
CG
5
CH
11
CE
CF
CI
16
CJ
CK
17
Green Ck
Black Point
15
17
Minudie Point
30
S
?
?
Nova Scotia
SHEPODY – BECKWITH FAULT
0
300 m
64°18'00"
45°46'00"
Pictou Group
Richibucto Formation
Salisbury Formation
Cumberland Group
Grande Anse Formation
Boss Point Formation
Geological boundary
Reverse fault
CK
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 65. Distribution of the Grande Anse, Salisbury, and Richibucto formations on Maringouin Peninsula and along strike at Minudie Point in Nova Scotia. St. Peter and Johnson (2009) give data on all spore localities except the one at Minudie Point.

Definition and Description: Norman (1941a) applied the name 'Grande Anse Formation' to a sequence of "reddish brown sandstone and shale" that crops out at Grande Anse on the western shore of Maringouin Peninsula. Gussow (1953) later correlated the rocks at Grande Anse with those on the eastern shore of Maringouin Peninsula, from Black Point north to Wood Point (Fig. 65; Plate 5).

In contradiction to Gussow (1953), the present authors do not consider the lithologically distinct rocks from Allen Creek to Wood Point as part of the Grande Anse Formation. The Grande Anse Formation is herein restricted to rocks in the type section along Grande Anse and rocks along strike on the eastern shore of Maringouin Peninsula, from Black Point north to, but excluding, Allen Creek. Strata on Allen Creek and at Wood Point are assigned herein to the Salisbury and Richibucto formations, respectively, of the Pictou Group. The Grande Anse Formation does not constitute the entire Pictou Group as envisioned by Gussow (1953); nor is it part of the Boss Point Formation as suggested by Browne (1991, p. 36).

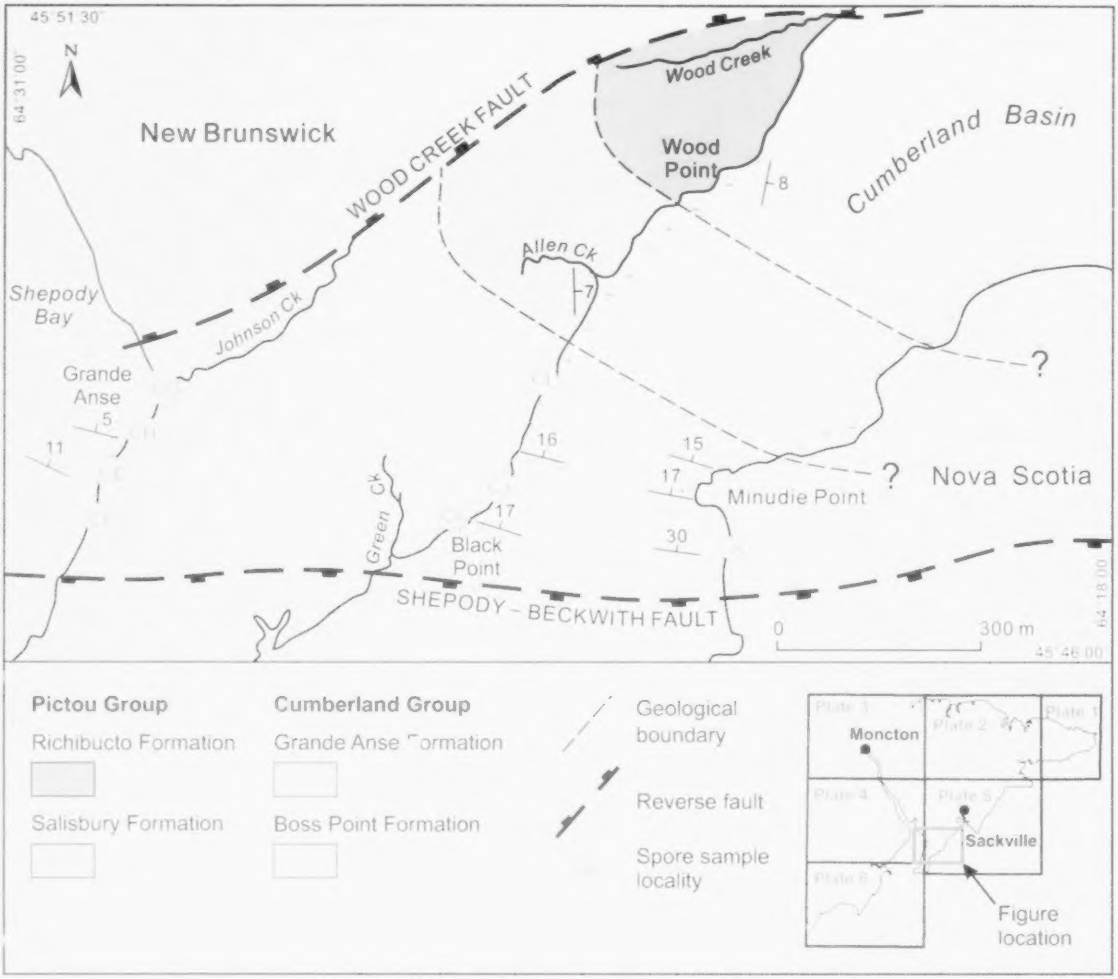

45°51'30"
64°31'00"
N
New Brunswick
WOOD CREEK FAULT
Wood Creek
Wood Point
Cumberland Basin
8
Allen Ck
7
Shepody Bay
Johnson Ck
Grande Anse
5
11
16
15
17
17
30
Green Ck
Black Point
Minudie Point
?
?
Nova Scotia
SHEPODY – BECKWITH FAULT
0
300 m
64°18'00"
45°46'00"
Pictou Group
Richibucto Formation
Salisbury Formation
Cumberland Group
Grande Anse Formation
Boss Point Formation
Geological boundary
Reverse fault
Spore sample locality
Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 65. Distribution of the Grande Anse, Salisbury, and Richibucto formations on Maringouin Peninsula and along strike at Minudie Point in Nova Scotia. St. Peter and Johnson (2009) give data on all spore localities except the one at Minudie Point.

Definition and Description: Norman (1941a) applied the name 'Grande Anse Formation' to a sequence of "reddish brown sandstone and shale" that crops out at Grande Anse on the western shore of Maringouin Peninsula. Gussow (1953) later correlated the rocks at Grande Anse with those on the eastern shore of Maringouin Peninsula, from Black Point north to Wood Point (Fig. 65; Plate 5).

In contradiction to Gussow (1953), the present authors do not consider the lithologically distinct rocks from Allen Creek to Wood Point as part of the Grande Anse Formation. The Grande Anse Formation is herein restricted to rocks in the type section along Grande Anse and rocks along strike on the eastern shore of Maringouin Peninsula, from Black Point north to, but excluding, Allen Creek. Strata on Allen Creek and at Wood Point are assigned herein to the Salisbury and Richibucto formations, respectively, of the Pictou Group. The Grande Anse Formation does not constitute the entire Pictou Group as envisioned by Gussow (1953); nor is it part of the Boss Point Formation as suggested by Browne (1991, p. 36).

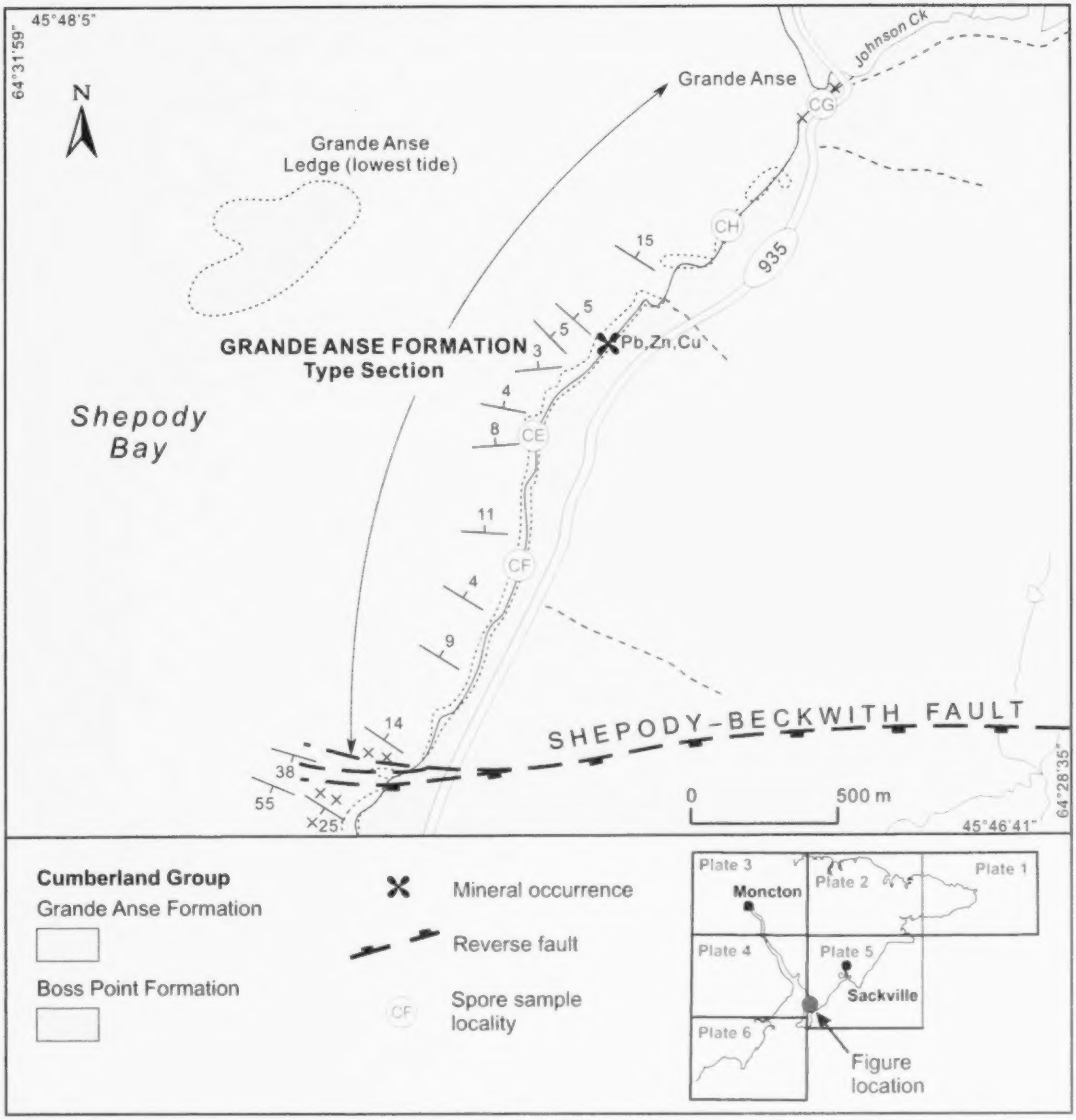

45°48'5"
64°31'59"
N
Grande Anse
Johnson Ck
CG
Grande Anse
Ledge (lowest tide)
CH
935
15
5
5
3
GRANDE ANSE FORMATION
Type Section
Pb,Zn,Cu
4
8
CE
Shepody
Bay
11
CF
4
9
14
38
55
25
SHEPODY–BECKWITH FAULT
0
500 m
45°46'41"
64°28'35"
Cumberland Group
Grande Anse Formation
Boss Point Formation
Mineral occurrence
Reverse fault
CF
Spore sample locality
Plate 3
Moncton
Plate 2
Plate 1
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 66. Geology map showing the type section for the Grande Anse Formation at Grande Anse on the east side of Shepody Bay.

The formation comprises pinkish grey and reddish brown, medium- to coarse-grained, chiefly quartz-rich arenite, pebbly arenite, and conglomerate (Fig. 68a, 68b). Fine-grained facies include reddish brown and minor bluish grey siltstone, mudstone, and very fine-grained to fine-grained sandstone. Repetitive fining-upward cycles comprising roughly subequal amounts of coarse- and fine-grained facies characterize the type section. The ratio of fine (less than fine-grained sand) to coarse is approximately 1.5, and the sandstone parts of the cycles are typically in the order of 5 m thick (Fig. 67). The finer parts of the cycles consist of very fine-grained, parallel- and ripple-laminated sandstone, red siltstone, and red to reddish brown or bluish grey, silty mudstone. The very fine-grained sandstone is locally cemented with carbonate. Mottled maroon and buff, sandy and silty calcareous paleosols with well-developed rooted zones are common features in the finer grained rocks (Fig. 68b).

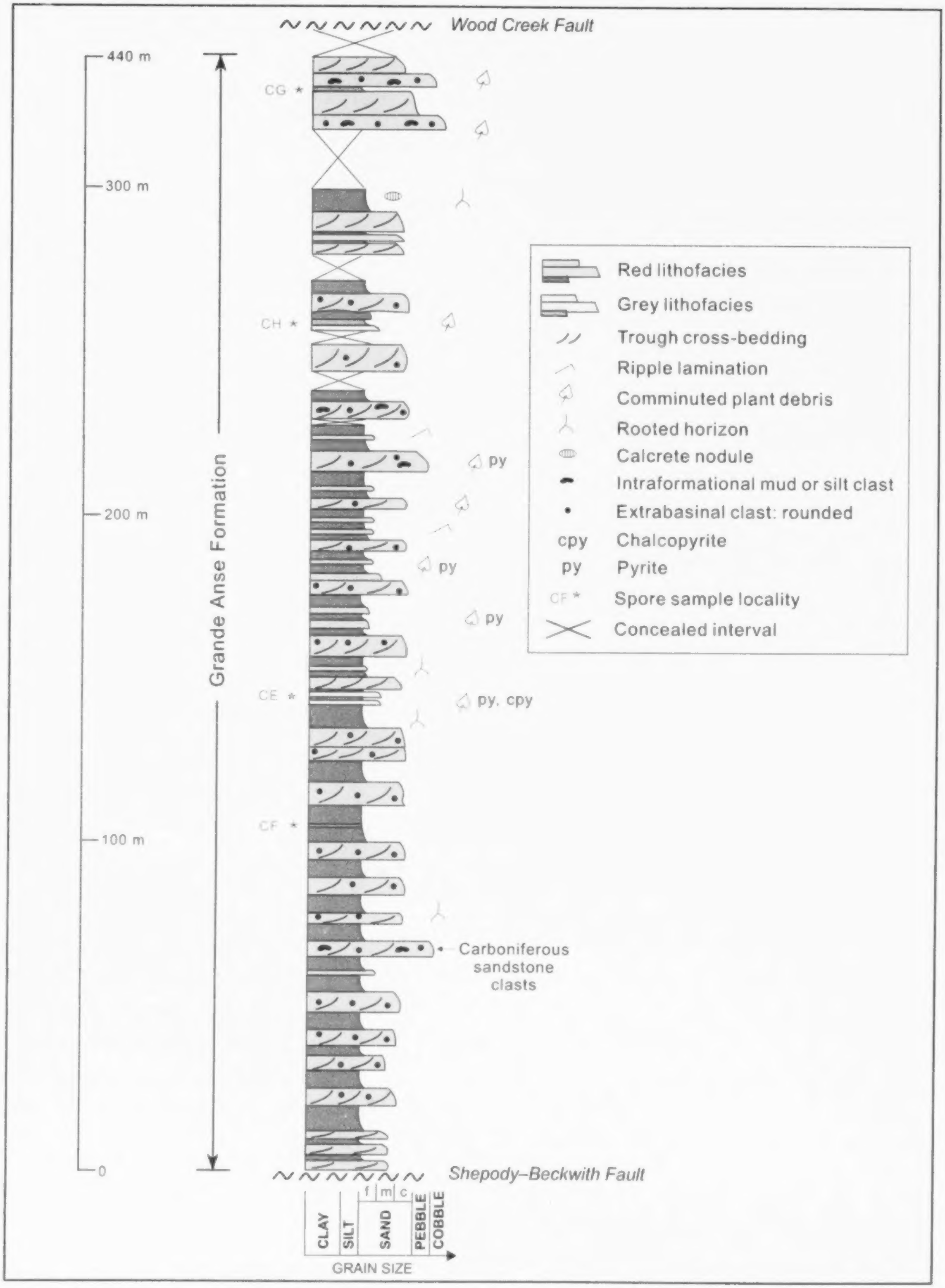

Wood Creek Fault
440 m
300 m
200 m
100 m
0
Grande Anse Formation
CG *
CH *
CE *
CF *
py
py
py
py, cpy
Carboniferous sandstone clasts
Shepody–Beckwith Fault
f
m
c
CLAY
SILT
SAND
PEBBLE
COBBLE
GRAIN SIZE
Red lithofacies
Grey lithofacies
Trough cross-bedding
Ripple lamination
Comminuted plant debris
Rooted horizon
Calcrete nodule
Intraformational mud or silt clast
Extrabasinal clast: rounded
cpy Chalcopyrite
py Pyrite
CF * Spore sample locality
Concealed interval

Figure 67. Generalized stratigraphy of the type section for the Grande Anse Formation at Grande Anse on the west side of Maringouin Peninsula.

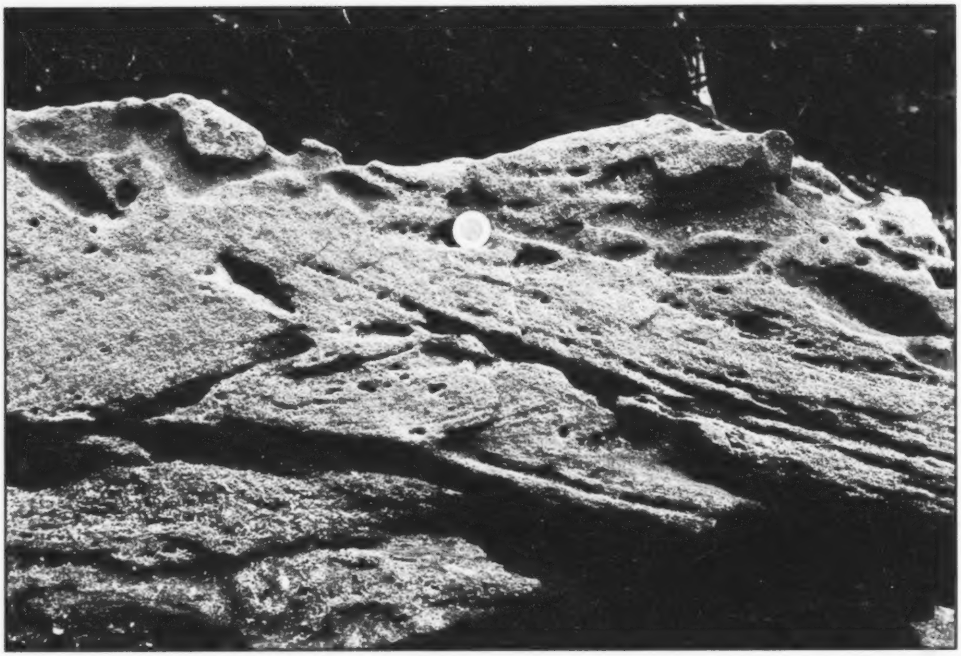


Figure 68a. Trough cross-bedded, pebbly quartzose arenite of the Grande Anse Formation at Black Point, east side of Maringouin Peninsula. Coin = 2.8 cm.

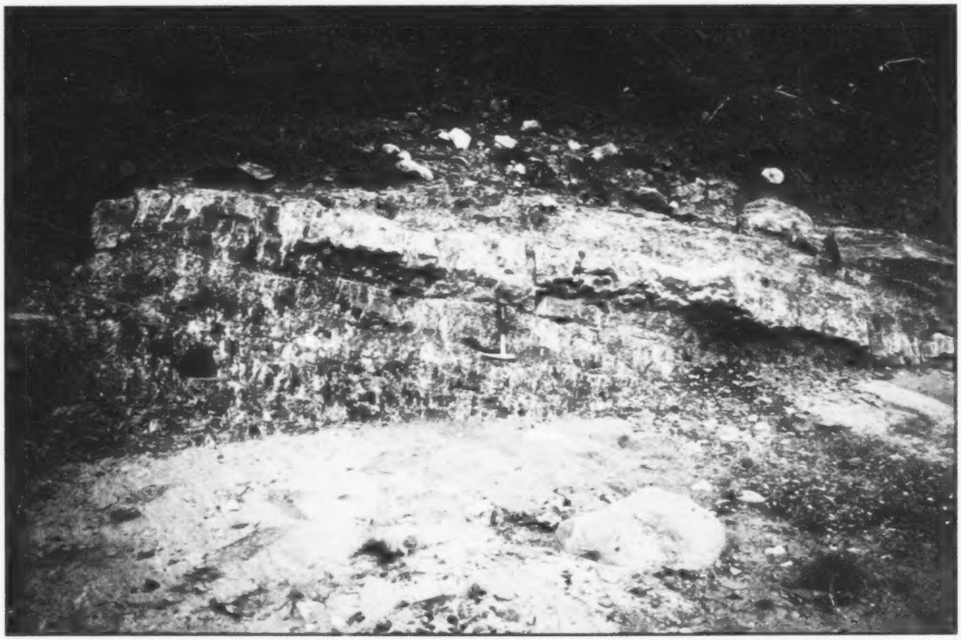


Figure 68b. Mottled, calcretized rooted zone in red overbank siltstones of the Grande Anse Formation at Black Point, east side of Maringouin Peninsula. Hammer for scale.

Medium-grained channel sandstones in the Grande Anse Formation commonly, but not exclusively, contain a high percentage of quartz and plot within the sublitharenite field on a QFR ternary diagram (Fig. 69). The samples chosen for point counting are biased in that a few were selected to demonstrate the presence of highly quartzose rocks in the formation. However, field observations indicate that medium-grained sandstones in the Grande Anse Formation have a range of compositions similar to that in the Boss Point Formation (Fig. 62). Textural and mineralogical maturity of sandstone in the Grande Anse Formation is apparent in thin section (Fig. 70).

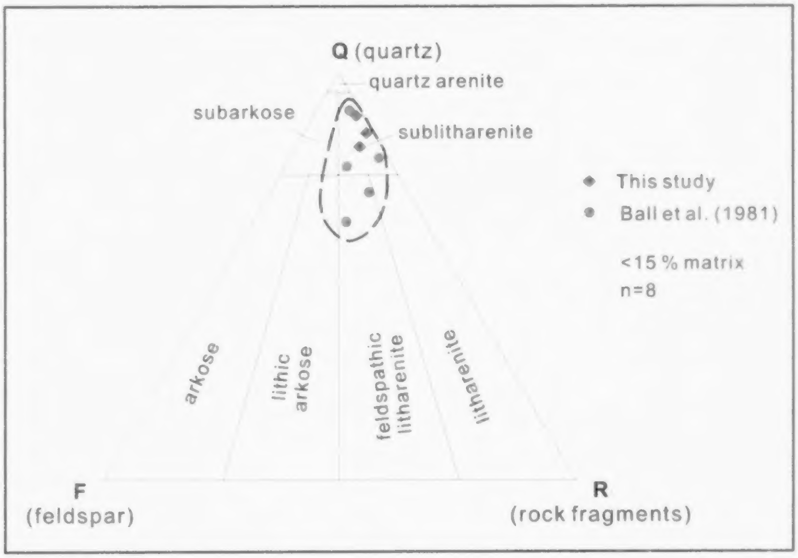


Figure 69. Ternary diagram showing sandstone composition of the Grande Anse Formation. QFR ternary base diagram after Folk (1974).

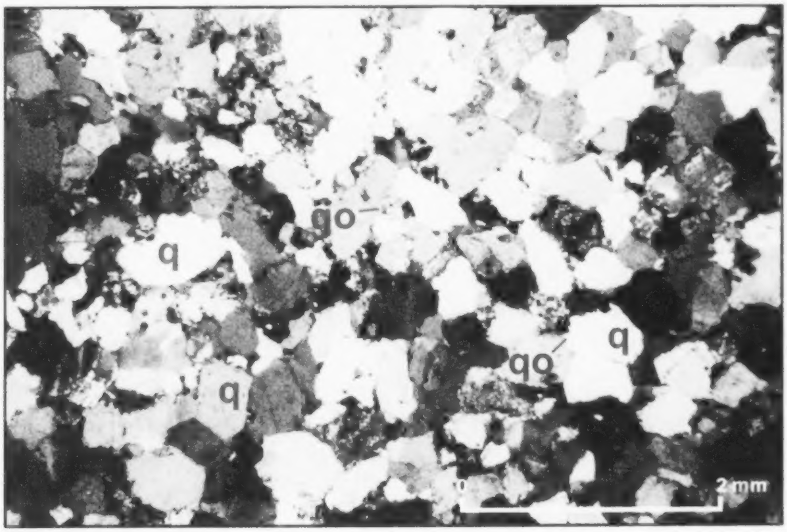


Figure 70. Photomicrograph of sublitharenite from the Grande Anse Formation at its type section along Grande Anse, west side of Maringouin Peninsula, showing abundant quartz **(q)** and authigenic quartz overgrowths (**qo**) on original detrital grains. Partly crossed nichols.

Medium- to coarse-grained, pebbly, trough cross-bedded sandstone is the most common coarse-grained facies and forms bodies typically less than 5 m thick. Well-rounded, pea-size quartz is the dominant clast in the pebbly sandstone, which also carries locally abundant red mudstone intraclasts and lithic fragments. Intraformational conglomerate at the base of the coarser cycles contain red and minor grey mudstone clasts as well as extrabasinal pebbles of quartz, mafic volcanic rocks, and maroon metasedimentary rocks.

A unique polymictic conglomerate occurs at Grande Anse, along strike at Black Point, and farther east at Minudie Point in Nova Scotia. This distinctive conglomerate, which may serve as a stratigraphic marker, contains a significant number of lithified grey sandstone clasts that resemble sandstones of the underlying Boss Point Formation (Fig. 67). The presence of proven clasts of Boss Point in the Grande Anse Formation would have significant stratigraphic and structural implications and is discussed below under ***Lateral Facies Relationships***. Van de Poll (1994) reports that Carboniferous sedimentary rocks locally comprise up to 37% of clasts in the Grande Anse conglomerate. In addition to having possible Carboniferous clasts, the conglomerate contains pebbles to small cobbles of rhyolite, quartz, plagioclase porphyry, quartzite, and metasedimentary rocks.

Distribution and Thickness: In New Brunswick the Grande Anse Formation is restricted to Maringouin Peninsula in the area overlying the Hastings Uplift (Fig. 6, 65, 71). It also occurs at Minudie Point in Nova Scotia, where it was mapped as Balfron Formation (Ryan and Boehner 1994). At extreme low tide, the formation is exposed at Grande Anse Ledge adjacent to the channel in Shepody Bay (Fig. 66).

The formation is at least 600 m thick on the east side of Maringouin Peninsula and is approximately 400 m thick in the type section on the west side of the peninsula (Fig. 67). The lower contact is faulted in both sections and the upper contact is either faulted or not exposed. The original depositional thickness of the formation is therefore not known.

Lower and Upper Boundaries: The basal and upper contacts are faulted in the type section on the west side of Maringouin Peninsula, and the base is faulted along strike at Black Point (Fig. 65–67; Plates 4, 5). The upper contact of the Grande Anse Formation is not exposed on the east side of Maringouin Peninsula. However, it is interpreted to be unconformable to disconformable with the overlying Salisbury Formation on the basis of 1) a marked difference in the east–west strike of the Grande Anse beds at Black Point versus the north–south strike of the Pictou beds at Allen Creek and Wood Point, and 2) the age discrepancy between the Westphalian A Grande Anse Formation and the latest Westphalian B strata of the lowermost Pictou Group.

Previous workers (Norman 1941a; Gussow 1953; van de Poll 1994) described the lower contact as having a pronounced angular unconformity, using as evidence the juxtaposition of moderately to gently north-dipping Grande Anse strata against almost vertical to steep south-dipping Boss Point beds near Johnson Mills (Fig. 72; Plate 4). Bell (1944) recognized the faulted nature of the Johnson Mills section but still interpreted the contact as unconformable, possibly because he considered the Grande Anse strata to be significantly younger than the Boss Point Formation. The faulted boundary at Johnson Mills is described in Chapter 3 under ***Shepody–Beckwith Fault***.

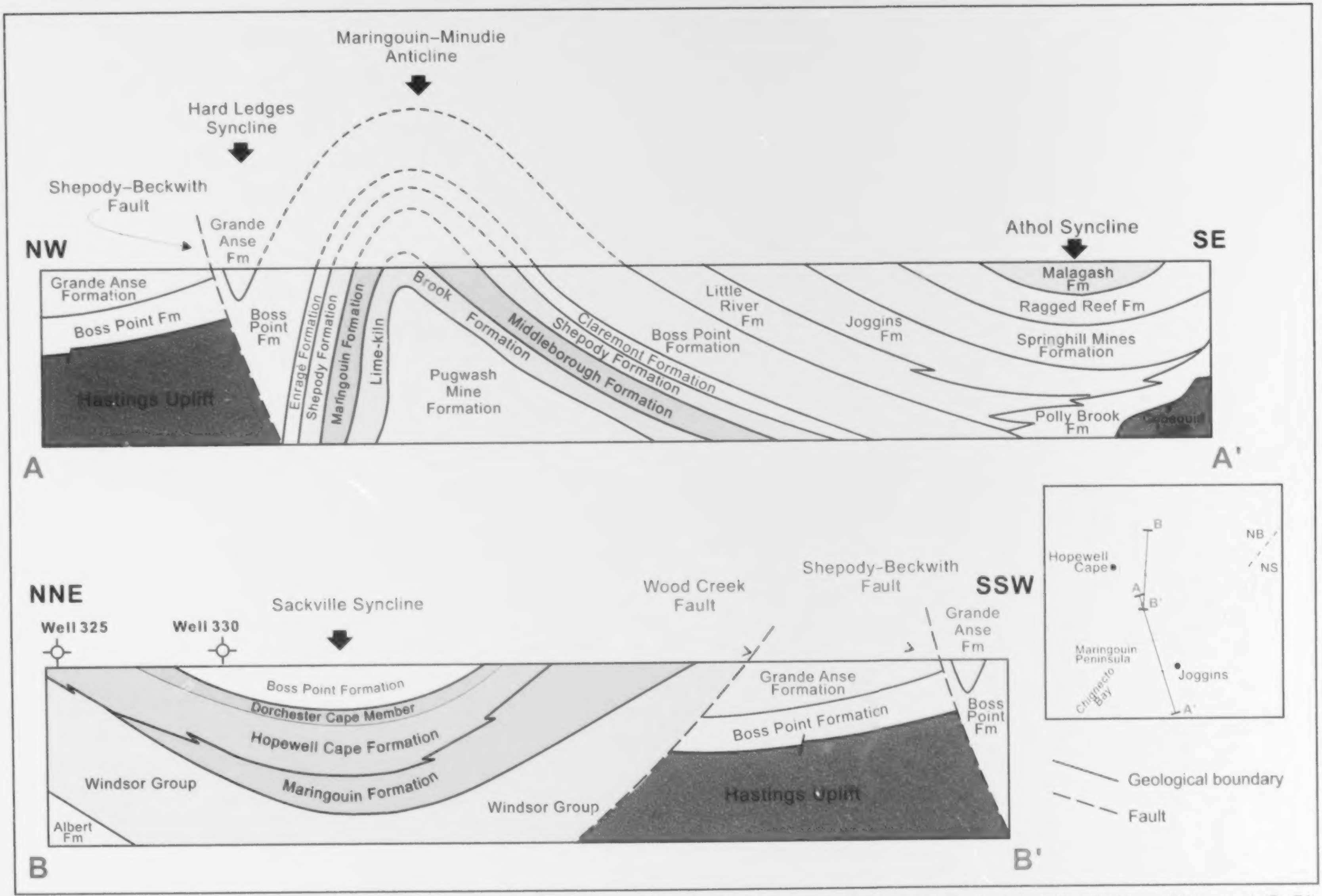

Maringouin–Minudie Anticline
Hard Ledges Syncline
Shepody–Beckwith Fault
Grande Anse Fm
NW
SE
Athol Syncline
Grande Anse Formation
Boss Point Fm
Hastings Uplift
Boss Point Fm
Enragé Formation
Shepody Formation
Maringouin Formation
Lime-kiln
Brook Formation
Pugwash Mine Formation
Middleborough Formation
Shepody Formation
Claremont Formation
Boss Point Formation
Little River Fm
Joggins Fm
Malagash Fm
Ragged Reef Fm
Springhill Mines Formation
Polly Brook Fm
Cobequid
A
A'
NNE
SSW
Well 325
Well 330
Sackville Syncline
Wood Creek Fault
Shepody-Beckwith Fault
Grande Anse Fm
Boss Point Formation
Dorchester Cape Member
Hopewell Cape Formation
Maringouin Formation
Windsor Group
Albert Fm
Windsor Group
Grande Anse Formation
Boss Point Formation
Boss Point Fm
Hastings Uplift
B
B'
B
Hopewell Cape
A
B'
NB
NS
Maringouin Peninsula
Chignecto Bay
Joggins
A'
Geological boundary
Fault

Figure 71. Simplified geological cross-sections of (A–A') Maringouin–Minudie Anticline and Athol Syncline (in part after Calder 1994); and (B–B') Sackville Syncline and Hastings Uplift.

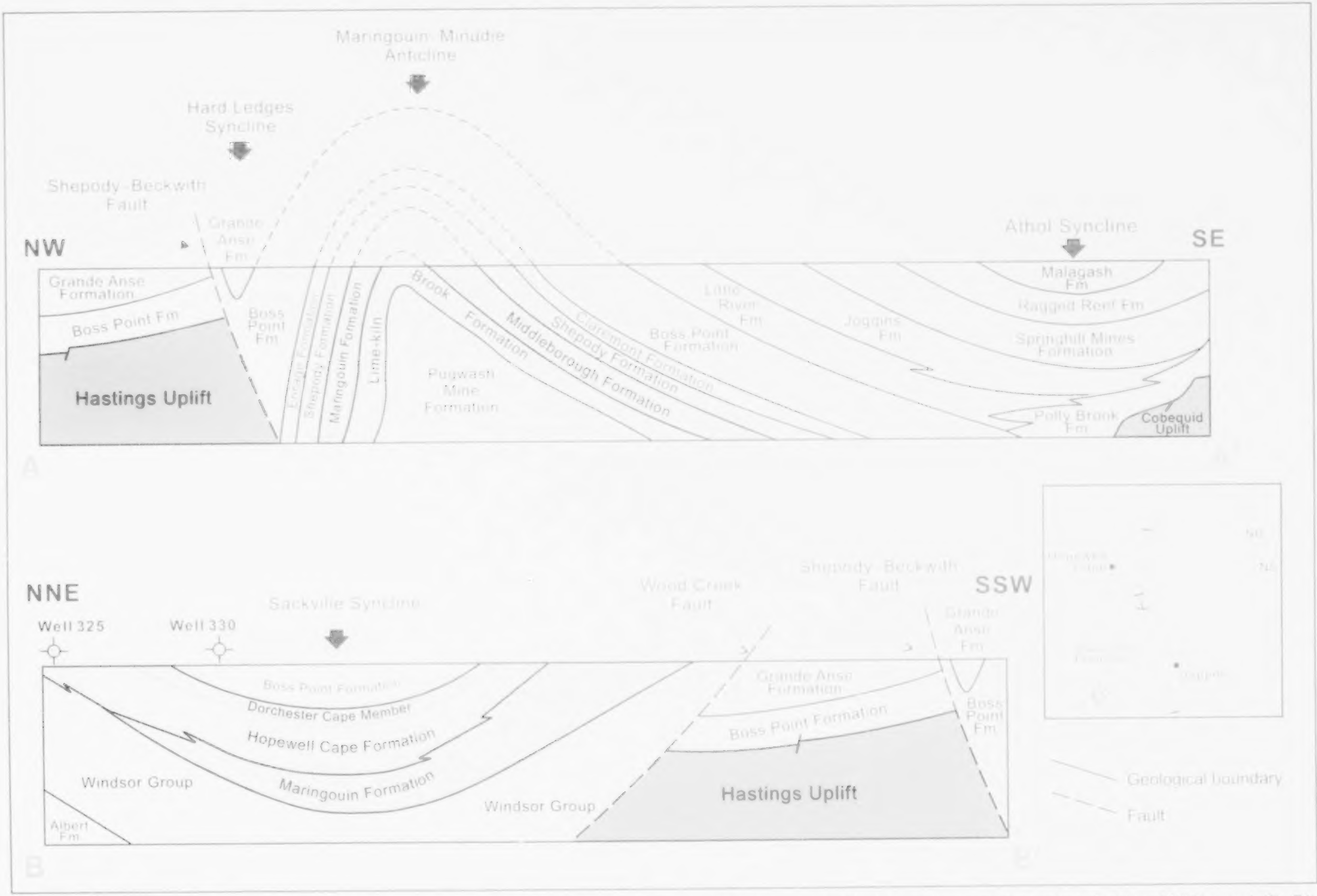
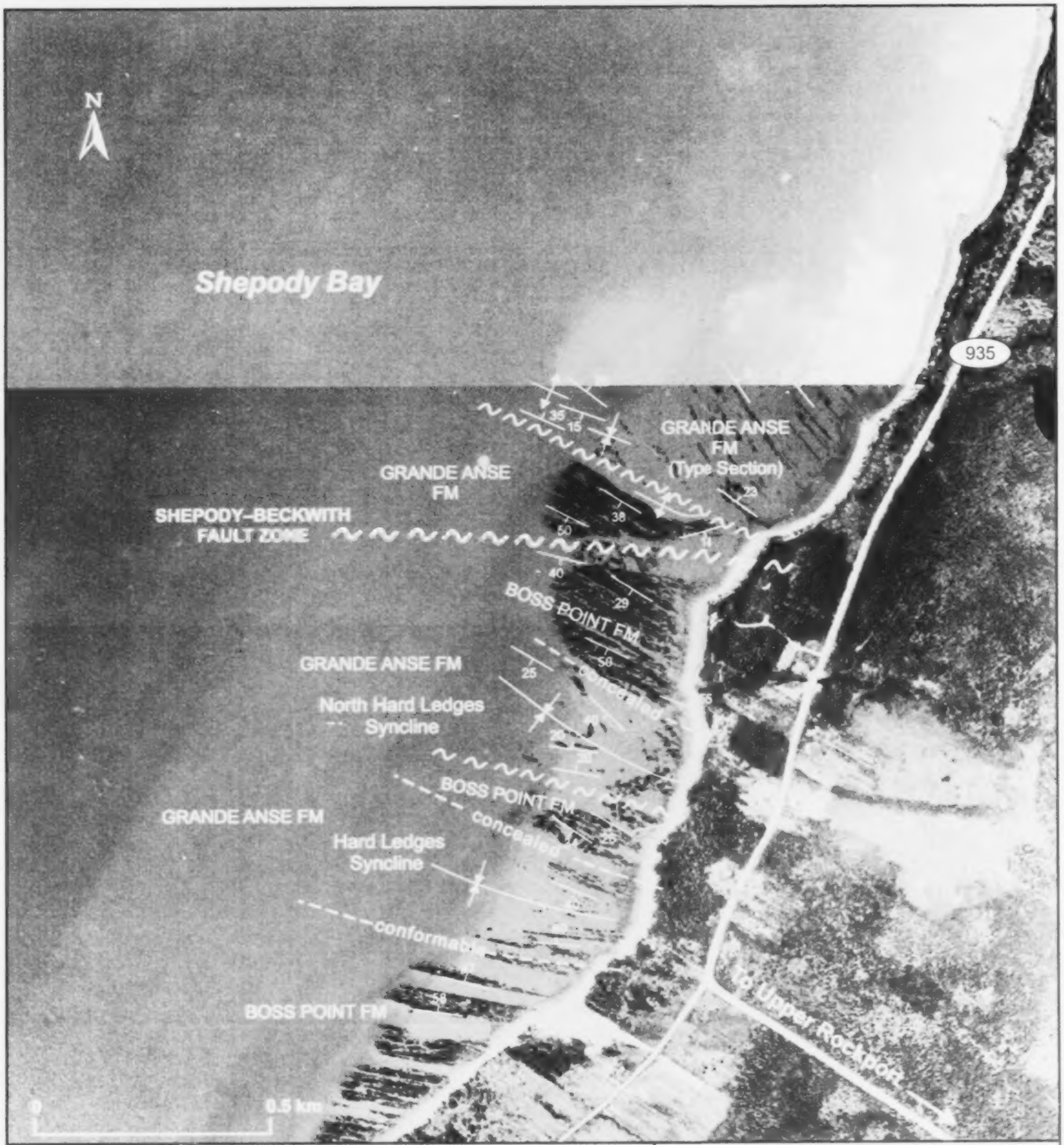

Maringouin–Minudie Anticline
Hard Ledges Syncline
Shepody–Beckwith Fault
Grande Anse Fm
Athol Syncline
NW
SE
Grande Anse Formation
Boss Point Fm
Boss Point Fm
Enrage Formation
Shepody Formation
Maringouin Formation
Lime-kiln
Brook Formation
Middleborough Formation
Shepody Formation
Claremont Formation
Boss Point Formation
Little River Fm
Joggins Fm
Malagash Fm
Ragged Reef Fm
Springhill Mines Formation
Pugwash Mine Formation
Hastings Uplift
Polly Brook Fm
Cobequid Uplift
A
A'
NNE
SSW
Well 325
Well 330
Sackville Syncline
Wood Creek Fault
Shepody–Beckwith Fault
Grande Anse Fm
Boss Point Formation
Dorchester Cape Member
Hopewell Cape Formation
Maringouin Formation
Windsor Group
Albert Fm
Windsor Group
Grande Anse Formation
Boss Point Formation
Boss Point Fm
Hastings Uplift
B
B'
NB
NS
Geological boundary
Fault

Figure 71. Simplified geological cross-sections of (A–A') Maringouin–Minudie Anticline and Athol Syncline (in part after Calder 1994); and (B–B') Sackville Syncline and Hastings Uplift.


N
Shepody Bay
935
GRANDE ANSE FM (Type Section)
GRANDE ANSE FM
SHEPODY–BECKWITH FAULT ZONE
BOSS POINT FM
GRANDE ANSE FM
North Hard Ledges Syncline
concealed
BOSS POINT FM
GRANDE ANSE FM
Hard Ledges Syncline
concealed
conformable
BOSS POINT FM
To Upper Rockport
0
0.5 km
35
15
23
38
50
10
40
29
58
25
58

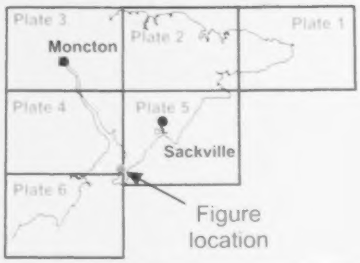


Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

Figure 72. Air photograph showing bedding ridges in the Boss Point and Grande Anse formations in the vicinity of the Shepody–Beckwith Fault, taken at low tide near Johnson Mills on Maringouin Peninsula.

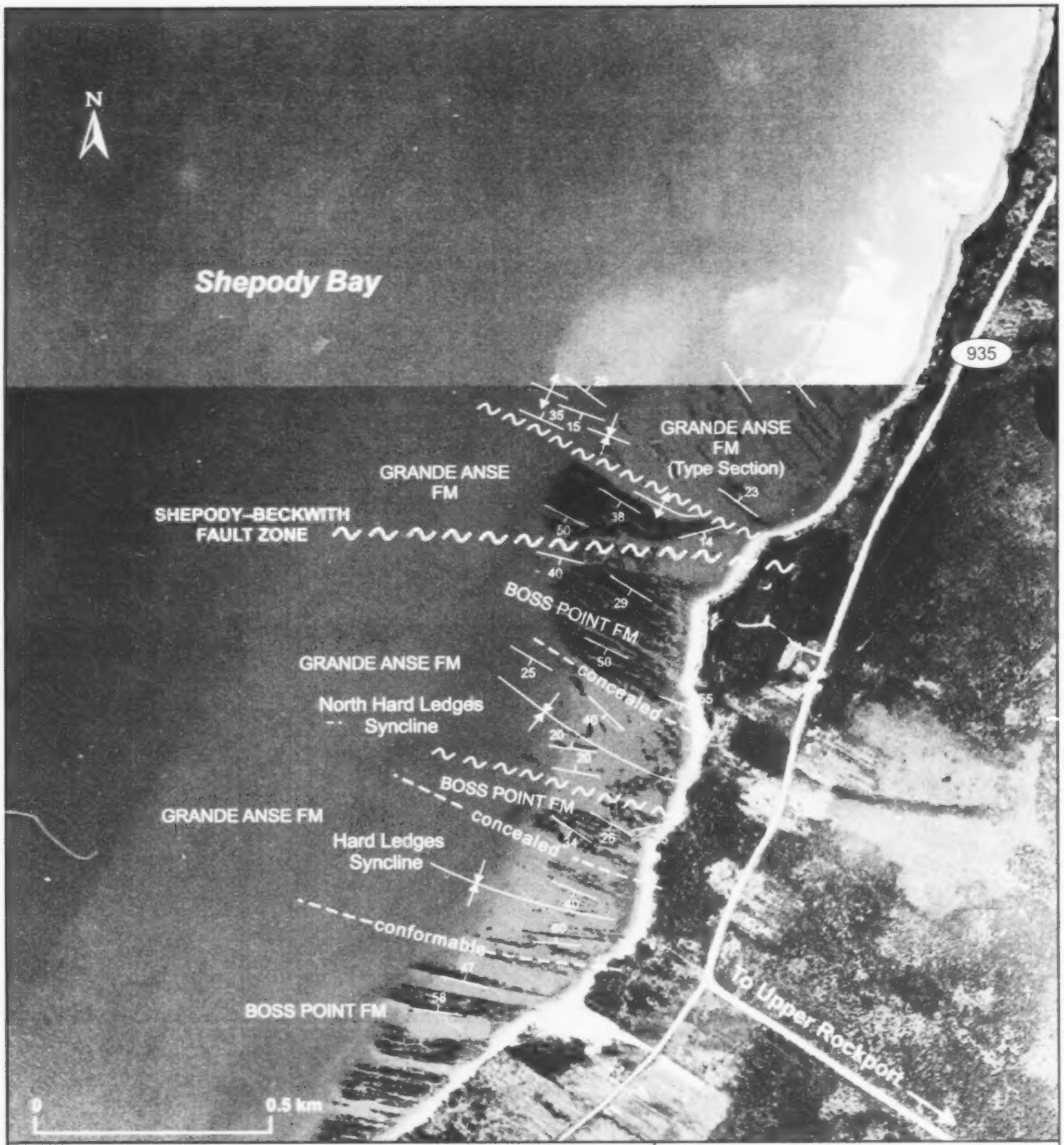

N
Shepody Bay
935
GRANDE ANSE FM (Type Section)
GRANDE ANSE FM
SHEPODY–BECKWITH FAULT ZONE
35
15
23
38
50
14
40
29
BOSS POINT FM
GRANDE ANSE FM
58
25
concealed
55
North Hard Ledges Syncline
46
20
20
BOSS POINT FM
GRANDE ANSE FM
concealed
Hard Ledges Syncline
26
conformable
47
58
BOSS POINT FM
To Upper Rockport
0
0.5 km

Figure 72. Air photograph showing bedding ridges in the Boss Point and Grande Anse formations in the vicinity of the Shepody–Beckwith Fault, taken at low tide near Johnson Mills on Maringouin Peninsula.

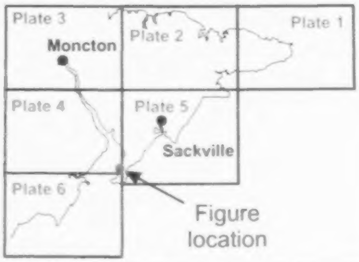


Plate 3
Plate 2
Plate 1
Moncton
Plate 4
Plate 5
Sackville
Plate 6
Figure location

South of the Shepody–Beckwith Fault, redbeds correlated with the Grande Anse Formation gradationally overlie the Boss Point Formation in the core of the Hard Ledges Syncline (Fig. 72; Johnson 1996). Similar redbed strata characterize the Little River Formation (Calder et al. 2005), which conformably overlies the Boss Point Formation on the corresponding south limb of the Minudie Anticline (an extension of New Brunswick's Maringouin Anticline) at Joggins in Nova Scotia (Fig. 6, 71).

Lateral Facies Relationships: The Grande Anse Formation appears to be a geographically restricted unit deposited near the northern margin of the Cumberland Subbasin. It is likely more closely related to the Cumberland succession in the Joggins area than to the Cumberland Group in the adjacent Sackville and Moncton subbasins. The greatly reduced thickness of the Cumberland Group in the Sackville and Moncton subbasins implies that those basins were topographically higher, or underwent relatively slower subsidence, than the Cumberland Subbasin in Nova Scotia.

The thickness of the sandstone intervals and interbedded variegated siltstone–mudstone sequences in the lower part of the Grande Anse Formation are comparable with lithologies in the Little River Formation (Calder et al. 2005), which occupies a similar stratigraphic position on the southern limb of the Minudie Anticline in Nova Scotia (Fig. 71). Interesting parallels can also be drawn between the coarser grained lithotypes in the Grande Anse Formation and the Polly Brook Formation, an alluvial fan deposit shed from the Cobequid Uplift along the southern margin of the Cumberland Subbasin (Ryan et al. 1991; Ryan and Boehner 1994, p. 30). Ryan and Boehner (1994) report that reworked Carboniferous quartz-rich sandstone clasts can be a significant component of conglomerates in the Polly Brook Formation, as is the case in some conglomerates of the Grande Anse Formation. The Polly Brook Formation is interpreted as laterally equivalent to the Little River, Joggins, and Springhill Mines formations (Fig. 71, section A–A'; also see Calder et al. 2005, their Fig. 4), although the Polly Brook Formation apparently underlies the Little River Formation east of the type area (Calder et al. 2005).

Despite the foregoing, a direct stratigraphic equivalency between the Grande Anse Formation and the Little River and Polly Brook formations is not suggested here, as the Grande Anse Formation lies on the opposite (northern) margin of the Cumberland Subbasin on the Hastings Uplift. On the basis of spore data (Dolby 1999b, 2000b), the authors interpret the Grande Anse Formation as being time-equivalent to the Little River, Joggins, Springhill Mines, and Polly Brook formations of the Cumberland Group. However, as Calder et al. (2005) point out, these spore ages must be viewed with caution.

Depositional Environment: The repetitive fining-upward cycles recorded by the Grande Anse Formation indicate deposition dominated by rivers (Miall 1992). The grain size and thickness of the conglomerate–sandstone channel sequences imply rivers of moderate size. The abundance of rooted overbank deposits with widespread paleosol development suggests deposition possibly on the lower reaches of an alluvial plain (Miall 1992).

Age: Spore assemblages in the Grande Anse Formation (Table 3) indicate a Westphalian A (Langsettian) age (Dolby 1999b, 2000b). Samples from seven different stratigraphic intervals, spanning virtually the entire thickness of the formation (Fig. 65, 67; Plates 4, 5), are characterized by abundant *Florinites* spp., especially *F. mediapudens*; *F. florinii* is also prominent. *F. florinii, Wilsonites* spp., and *Cananoropollis mehtae* make their first appearance in the Langsettian-age *G. listeri* Goniatite Band in Europe (Fig. 56; Dolby 1999b). Bell (*in* Gussow 1953) reported plant fossils in the formation near Green Creek, which he considered to be late Cumberland or early Pictou. An eighth sample, taken at spore locality 169 (Plate 4) near the base of redbeds in the core of the Hard Ledges Syncline, yields an age of late Namurian (Yeodonian) to early Westphalian A (early Langsettian) (Dolby 2000b), suggesting those beds may be older than the Grande Anse Formation in the type section.

Relationship to Previous Stratigraphy: The Grande Anse Formation was introduced by Norman (1941a) to describe rocks on the west side of Maringouin Peninsula at Grande Anse. Gussow (1953) extended the unit to include rocks as far north as Wood Point (Plate 5), which were not mapped by Norman (1941a). Gussow also abandoned the formation name and included the Grande Anse strata in the Pictou Group, believing they spanned the entirety of Pictou time. Gussow's argument was based on macrofloral evidence (Bell *in* Gussow 1953, p. 1761), which indicated that the section of rocks at Green Creek were late Cumberland or early Pictou whereas those at Wood Point were late Pictou.

Van de Poll (1994) followed Gussow and assigned the Grande Anse Formation to the Pictou Group. In contrast, Browne (1991, p. 36) placed the rocks originally assigned to the Grande Anse Formation by Norman (1941a) in the Boss Point Formation, although he provided no rationale for doing so. An improved understanding of the regional lithostratigraphy indicates that the Grande Anse Formation as originally defined by Norman (1941a) is a valid lithostratigraphic unit and should be reinstated. The formation incorporates strata mapped as Balfron Formation by Ryan and Boehner (1994) at Minudie Point in Nova Scotia (Fig. 65).

PICTOU GROUP

Bell established the terms 'Pictou Series' (1926) and 'Pictou Group' (1944) to describe more than 2200 m of red and grey, micaceous, impure quartz sandstone and arkosic grits, red shale, and mudstone on the West Branch of River John in Nova Scotia. Gussow (1953) was first to apply the name 'Pictou Group' to the rocks overlying the Boss Point Formation in New Brunswick. Strata assigned to the Pictou Group encompassed Zone 3 of the Petitcodiac Series (Wright 1922) and the upper part of the Petitcodiac Group (Norman 1941a, 1941b). Gussow (1953) subdivided the Pictou Group into the Salisbury, Scoudouc (now abandoned), Richibucto, and Tormentine formations. Subsequently, most authors including van de Poll (1970, 1972, 1994), McLeod and Ruitenberg (1978), and Ball et al. (1981) have followed Gussow's (1953) nomenclature.

Ryan et al. (1991) and Ryan and Boehner (1994) made an attempt to revise the Pictou and Cumberland groups in the type areas in the Cumberland Subbasin of Nova Scotia. They adjusted the base of the Pictou Group upward to exclude the grey sandstones of the Malagash Formation, which were originally assigned to the group by Bell (1926, 1944). Nonetheless, they did acknowledge the utility of Bell's (1944) approach to group subdivision based on tectonic history (unconformities) and the vertical distribution of plant species (age). In contrast with Ryan et al. (1991), Giles and Utting (1999b, 1999c) use a stratigraphic-sequence approach, which identifies groups of strata on the basis of their bounding discontinuities (allostratigraphic units). The latter authors propose a regionally significant and widespread stratigraphic break at the level of the early Westphalian B throughout the Maritimes Basin, and they recommend assigning all strata above this unconformity to the Pictou Group. Therefore, their approach closely agrees with Gussow's (1953) definition of the Pictou Group in New Brunswick.

In New Brunswick the Pictou Group (Fig. 8) comprises the Salisbury (and equivalent formations in the Minto area), Richibucto, and Tormentine formations, as originally proposed by Gussow (1953). Although the Westphalian B unconformity marks the base of the Pictou Group in New Brunswick, this group of strata can also be defined by a set of lithological characteristics. The Pictou Group as defined herein is synonymous with the Morien Group in the Sydney Basin on Cape Breton Island (Boehner and Giles 1986).

The Pictou Group in New Brunswick displays a gradational upward change in sandstone composition and morphology. This is reflected in a decrease in quartz and an increase in mica content in the coarser grained sandstones, from the Salisbury Formation upward through the Tormentine Formation. Sublitharenites, subarkose, and quartz arenite are typical of both the Cumberland Group (Fig. 62, 69) and basal Pictou Group (Fig. 73a). However, sandstones with a high quartz content (>75%) are not typically found in the Richibucto and Tormentine formations (Fig. 73b, 73c). The mica content of the sandstone also appears to be diagnostic. As determined by petrography, muscovite and minor biotite make up less than 1% of all detrital grains in the Salisbury Formation, 2% to 3% in the Richibucto Formation, and 2% to 8% in the Tormentine Formation. Visual field estimates suggest that the mica content of Richibucto sandstones can also be very high and is likely to have an upper range similar to that in the Tormentine Formation. Browne (1991) notes that mica comprises a very low percentage of the detrital material in medium-grained sandstones in the Grande Anse and Boss Point formations of the Cumberland Group, an observation supported by field work conducted by the present authors.

Sandstones of the Pictou Group exhibit a wide range of compositions, and the absence of either coarse-grained mica or quartz-rich sandstone within individual sand bodies does not necessarily or definitively indicate a particular stratigraphic horizon or formation. However, coarse-grained detrital muscovite in medium-grained sandstone is diagnostic of the upper part of the Pictou Group in New Brunswick. The presence of coarse detrital muscovite and the subordinate quantity of quartz in sandstones of the Richibucto and Tormentine formations distinguish them from the underlying Salisbury Formation. Equally noteworthy is the regional uniformity of the Richibucto and Tormentine formations, likely a consequence of decreased paleogradients (approaching base level) and waning tectonism during the latter part of the Carboniferous.

The placement of the Cumberland–Pictou boundary in the present report differs from that of Ryan et al. (1991) and Ryan and Boehner (1994). This presents a challenge in correlating the Pictou Group in New Brunswick with that in Nova Scotia and warrants the following discussion.

Several lines of evidence suggest that the Richibucto Formation is synonymous with the grey beds and at least some of the overlying redbeds of the Pictou Group as defined by Bell (1944) in the Cumberland Subbasin of Nova Scotia. Ryan and Boehner (1994) assigned the grey beds to their newly introduced Malagash Formation and the overlying redbeds to the Balfron,

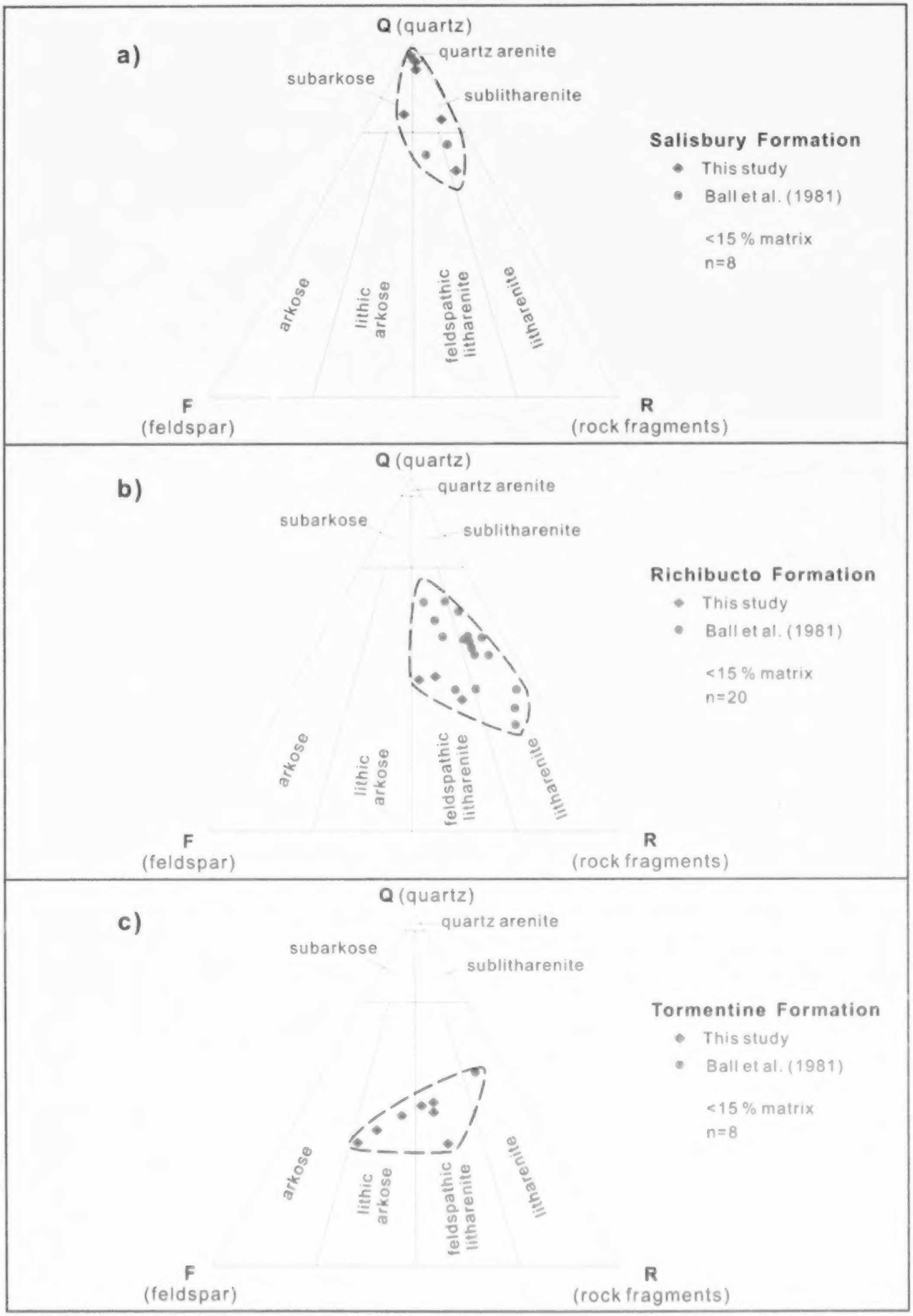


Figure 73. Ternary diagrams showing sandstone compositions in the Pictou Group: a) Salisbury Formation, b) Richibucto Formation, c) Tormentine Formation. QFR ternary base diagram after Folk (1974).

Tatamagouche, and Cape John formations. This is problematic, as the Malagash Formation is assigned to their Cumberland Group and the Balfron Formation to their Pictou Group. Ryan et al. (1991) acknowledged the difficulty with their revisions, as the Malagash Formation is transitional with the Balfron and the former represents the historical basis for including the grey fluvial sandstones in the Pictou Group (Bell 1926, 1944). Using the lithological criteria of Ryan and Boehner (1994), the Pictou Group in New Brunswick would include only the Tormentine Formation, leaving the underlying Richibucto and Salisbury formations in the Cumberland Group. Placing the Tormentine strata into a different group than the Richibucto Formation, where colour is nearly the only distinguishing difference, illustrates the inherent difficulties in the classification scheme advanced by Ryan and Boehner (1994; Table 8).

Table 8. Criteria developed by Ryan and Boehner (1994) to distinguish between rocks of the Cumberland and Pictou groups.

Criteria	Cumberland Group	Pictou Group	Richibucto Formation	Tormentine Formation	Malagash Formation	Balfron Formation
Coal-bearing	Generally	Rarely	Rarely	Absent	Rarely	Absent
Red facies	Subordinate	Dominant	Subordinate	Dominant	Subordinate	Dominant
Grey facies	Dominant	Subordinate	Dominant	Subordinate	Dominant	Subordinate
Conglomerate	Locally abundant	Rare	Rare	Rare	Rare	Rare
Fine facies	Subordinate –subequal	Dominant	Subordinate –subequal	Subordinate –subequal	Subordinate –subequal	Subordinate –subequal
Lateral facies variation	Rapid, diverse	Limited	Limited	Limited	Limited	Limited

One of the key problems with this scheme is the dependence of one criterion on another (i.e., if red lithofacies are dominant then grey lithofacies will be subordinate and the unit will probably not be 'generally coal-bearing'). For a lithostratigraphic approach to be useful, it cannot rely heavily on colour or on whether a unit is rarely (Pictou) or generally (Cumberland) coal-bearing. A case in point is the Westphalian D to Stephanian Sydney Mines Formation. The formation is clearly correlative with strata assigned to the Pictou Group by Ryan and Boehner (1994) but also contains eastern Canada's pre-eminent economic coal seams. Although the dominance or lack of fine lithofacies and lateral variation are somewhat mutually dependent, these criteria are useful as they can reflect the tectonic regime during deposition of related groups of strata.

If the criteria of Table 8 are applied, the Richibucto and Tormentine formations have Pictou-like characteristics because both contain minor conglomerate (excluding intraformational types) and exhibit limited lateral facies variation. Yet the fine lithofacies in both formations are subordinate to subequal and therefore are Cumberland-like. The presence of minor coal in the Richibucto Formation could be considered a feature of either the Pictou ('rare coal') or the Cumberland ('generally but not everywhere coal-bearing'). Johnson (1996) presented lithological criteria such as sandstone composition and texture and sandstone sequence architecture, demonstrating that the Richibucto Formation should be included in the Pictou Group, in accordance with earlier workers. Unifying lithological characteristics are discussed below and under ***Richibucto Formation*** that imply a kinship between the Richibucto and Tormentine formations, one that precludes separating them into different groups.

Units in the Cumberland Subbasin of Nova Scotia that likely would be correlative with the lower Pictou Group in New Brunswick include the Spicers Cove beds in the upper Ragged Reef Formation (Cumberland Group of Ryan and Boehner 1994) and grey beds mapped as Malagash Formation in the core of the Athol Syncline. Upper Pictou correlatives in the Cumberland Subbasin of Nova Scotia would include the Malagash Formation (north of the Beckwith Fault and equivalent to Bell's Pictou grey beds), as well as the Balfron, Tatamagouche, and Cape John formations. The Prince Edward Island redbeds of van de Poll (1989) exhibit similar compositions and bedding styles and could be included in the Pictou Group as well. The disconformity between the Cumberland and Pictou groups, as defined herein, would likely lie within the Ragged Reef Formation as defined by Ryan and Boehner (1994) in the Cumberland Subbasin of Nova Scotia.

Salisbury Formation

Authors: Gussow (1953); revised by Carr (1968) and herein.

Type Section: Williams et al. (1985), referencing Gussow (1953), proposes a type section along Petitcodiac River in the community of Salisbury, Westmorland County (NTS 21 I/03). The section and village lie just west of the report area (Fig. 6).

Reference Section: A reference section is designated herein on Little River, Albert County, from approximately 6 km south of the Nixon Road just north of Parkindale (NST 21 H/15; Plate 4) north to the Synton area (NTS I/02; Plate 3).

Definition and Description: The Salisbury Formation consists of red and lesser grey sandstone– conglomerate, siltstone, and mudrocks. The formation disconformably overlies the Grande Anse Formation and Cole Point Member of the Boss Point Formation and is conformably overlain by the Richibucto Formation. It includes rocks on Allen Creek on Maringouin Peninsula (Fig. 65) previously assigned to the Grande Anse Formation (Gussow 1953) but excludes those of the Scoudouc Formation assigned to the Salisbury Formation by Carr (1968). The name 'Scoudouc Formation' was previously abandoned by Johnson (1995, 1996).

Typical lithologies within the Salisbury Formation are brownish red to brick red, mottled siltstone and mudstone, grey and dusky greyish maroon, very fine-grained to fine-grained, ripple-laminated sandstone and fine- to medium-grained, trough cross-bedded sandstone and conglomerate. Greyish green, cross-laminated, carbonaceous, very fine-grained sandstone and grey silty mudstone with comminuted plant material are less common. Trough cross-bedded channel sequences up to 20 m thick consist of pinkish grey, red and buff sandstone, pebbly sandstone, and intraformational and polymictic conglomerate. Lag conglomerates at the base of the channel sequences contain red and grey mudstone intraclasts plus extrabasinal quartz pebbles. Slightly less abundant is texturally immature, polymictic conglomerate containing subrounded to angular clasts of quartz, felsite, flow-banded rhyolite, and mafic rocks, and sedimentary schistose rocks. The polymictic conglomerate is extremely friable in weathered exposures due to the high clay–mud content of the matrix (Fig. 74). Coalified plant debris and rare thin coals, none greater than 10 cm, are also present.

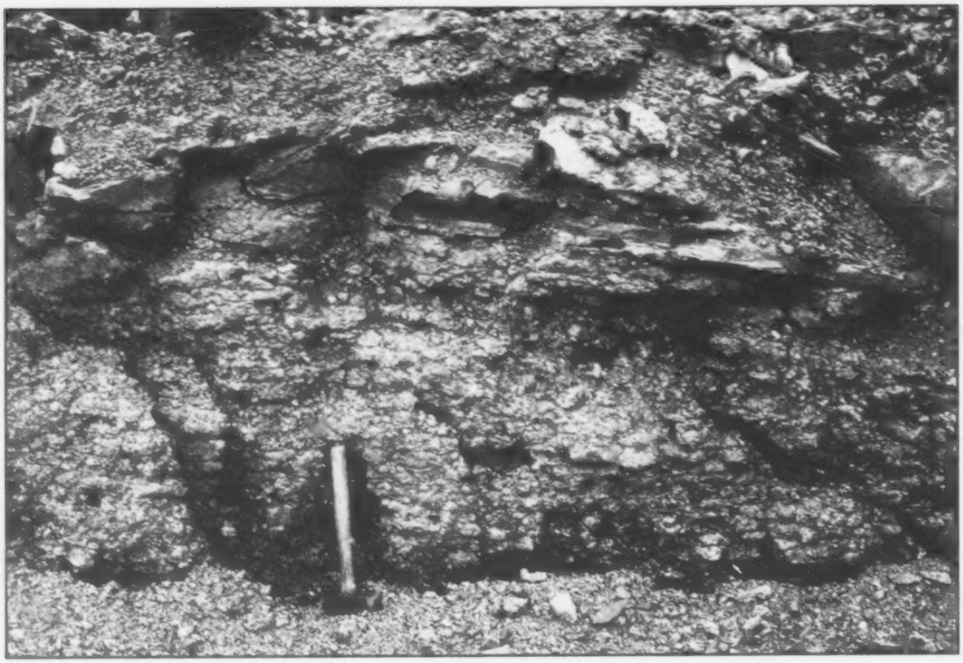


Figure 74. Friable polymictic conglomerate and sandstone of the Salisbury Formation off Burrell Road east of Little River.

Calcrete nodules occur locally near the top of the formation on Little River. Medium-grained sandstones in the Salisbury exhibit a range of compositions, including sublitharenite, subarkose, litharenite, feldspathic litharenite, and quartz arenite (Fig. 73a). Although sandstones containing greater than 75% quartz are uncommon in the Salisbury Formation, they are not recorded at all in the overlying Richibucto Formation. Field observations and sandstone petrography (Fig. 75) support Gussow's (1953) recognition of quartz-rich sandstones in the Salisbury and other basal Pictou formations such as the Minto Formation.

A distinguishing feature of the Salisbury Formation is the presence of silica-cemented paleosols or "ganisters" (*sensu* Percival 1983). Ganisters are formed as the result of prolonged leaching of clay and other fine material during pedogenesis and are further developed by later diagenetic quartz cementation (Hampson et al. 1997). On Little River, the silica-cemented paleosols attain thicknesses of up to 1 m but are incompletely exposed. The paleosols are extremely well indurated and have an irregular, nodular weathered surface. The best exposures are on Little River south-southeast of the community of Salisbury. They occur at several different stratigraphic levels, most notably in the lower part of the formation. Johnson (1996) suggests these beds are analogous to the siliceous duricrusts described by Gibling and Rust (1992) from the Waddens Cove Formation (Morien Group) in the Sydney Subbasin. The paleosols consist of mottled maroon and buff mudstone to very fine-grained sandstone that are cemented to various degrees with silica. Thin sections demonstrate they are composed of microcrystalline quartz and organic material. Polygonal crack patterns in the exposures on Little River attest to the well-drained conditions during formation. Roughly circular masses, up to 40 cm in diameter, of variegated, silicified rock in the beds have an internal columnar structure that bears a striking resemblance to coalified trees and are tentatively interpreted to be in situ lycopod stumps.

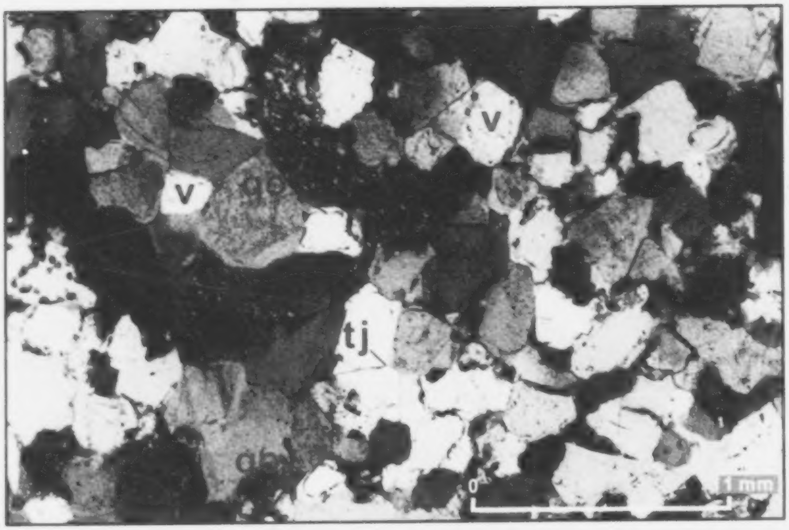


Figure 75. Photomicrograph of sublitharenite from the Salisbury Formation on Little River near Salisbury. View shows abundant subhedral to euhedral authigenic quartz overgrowths (**qo**) and pressure solution features such as triple junctions (**tj**). Vacuoles (**v**) indicate a hydrothermal vein source for the quartz. Partly crossed nichols.

A newly recognized grey sandstone member, herein named the 'Colpitts Settlement Member,' is exposed at the base of the Salisbury Formation along Little River south of Colpitts Settlement. It comprises medium- to coarse-grained, trough cross-bedded, grey and greenish grey feldspathic quartzose arenite, pebbly sandstone, and polymictic conglomerate; and brownish red siltstone, shale, and fine- to medium-grained feldspathic arenites with brownish red and locally greenish grey mudstone intraclasts. Polymictic conglomerates typically have a coarse-grained lithic arenite matrix and contain subrounded to subangular pebbles (up to 2.5 cm) of pink rhyolite, flow-banded rhyolite, quartzite, quartz, green siltstone, fine-grained granite, dark red chert, and intraformational mudstone. The member is recognized only in the westernmost part of the map area on Little River and Turtle Creek. The sandstones in the member locally contain extremely abundant coalified plant remains and lycopods up to 30 cm diameter. On Little River, the grey sandstones of this member are overlain by red and lesser grey, very fine-grained to fine-grained sandstone, mottled red siltstone and mudstone, and relatively minor, pinkish grey to red, trough cross-bedded sandstone, pebbly sandstone, and conglomerate. Rocks in this lower grey sandstone member were previously included in the Boss Point Formation by Gussow (1953). Their placement in the Salisbury Formation followed from an extensive palynological sampling of the Little River section (Dolby 1999b); see ***Lower and Upper Boundaries***, below.

Distribution and Thickness: The Salisbury Formation is widely distributed but very poorly exposed. From the Little River reference section, it extends northeast to Moncton, thence east and south to the Sackville area (Plates 2–5). Northeast of Sackville, the Salisbury Formation is downthrown against the Mabou Group and Boss Point Formation along the Tantramar Fault between Westcock and Upper Point de Bute. Map relationships suggest the formation overlies the Boss Point Formation on the southeast side of Fort Cumberland Ridge from Mount Whatley to Halls Hill, where it is interpreted to underlie the marshland on the hanging wall of the Wood Creek Fault (Fig. 6, 8). On the south side of the Wood Creek Fault, it is exposed near the mouth of Allen Creek (Fig. 65).

The most reliable thickness estimates come from boreholes. The formation is thin over parts of the Westmorland Uplift. For example, approximately 290 m of Salisbury strata are present in Well 146 (Fig. 13, 55), which was spudded in the formation just west of Colpitts Settlement. In the Malakoff area just north of the basement exposure near Calhoun (Plate 3), the formation is less than 100 m thick. It thickens to the south into the Sackville Subbasin and reaches about 800 m thick on the north limb of the Sackville Syncline in the Mount View and Upper Sackville area. The thickness is about 500 m in boreholes from the Port Elgin area (Fig. 55).

Lower and Upper Boundaries: In most places, the basal contact of the Salisbury Formation is positioned at the base of a succession dominated by fine-grained redbeds and thin units of red, pink, and grey sandstone, quartzose sandstone, and pebbly sandstone. In the Sackville Subbasin, this contact is exposed in a roadcut about 5 km northwest of Sackville at the junction of Highway 2 and Walker Road (Plate 5). The contact there is placed at the top of the uppermost grey sandstone bed of the Boss Point Formation, which is exposed on the east side of the westbound on-ramp of Highway 2. The overlying basal strata of the Salisbury Formation are reddish brown sandstone, pinkish quartz-pebble sandstone, and mottled, reddish brown mudstone and siltstone containing siliceous paleosols. A similar lithostratigraphy appears in a quarry near British Settlement about 3.5 km south of Sackville and in boreholes near Port Elgin (Fig. 55). Bedding attitudes in the Salisbury Formation and underlying Boss Point Formation are parallel, but, as discussed below, spore ages suggest a significant stratigraphic break at the contact.

Numerous miospore assemblages dated during the course of work for this report illustrate how the historical assignment of strata to the Boss Point Formation versus the overlying Salisbury Formation has presented a mapping challenge. The presence of quartz-rich sandstones and, locally, thick grey channel sandstones at the base of the Salisbury Formation in places makes it difficult to identify the boundary with the Boss Point Formation. This has led to several interpretations of the contact location (compare Gussow 1953; van de Poll 1973b; McLeod and Ruitenberg 1978).

One example can be demonstrated in the Little River area in the Moncton Subbasin (Plate 4). Spore analyses revealed that the upper part of Gussow's (1953) "Boss Point Formation" along Little River yielded spores typical of the late Westphalian B to early Westphalian C transition, indicating the existence of a previously unrecognized sequence of grey, multistoried, channel sandstone at the base of the Pictou Group (Colpitts Settlement Member of the Salisbury Formation). This presented a significant problem, because the grey Salisbury sandstones are lithologically similar to the underlying and somewhat older sandstones of the Boss Point Formation, highlighting the difficulty in reconciling the lithostratigraphy and biostratigraphy in this area. However, analyzing the miospore assemblages and re-examining exposures in the Little River section have helped to recognize a subtle lithological difference between the two sequences. The following discussion summarizes the pertinent palynological data, further details of which are in St. Peter and Johnson (2009).

At the Little River section, the lower contact of the Colpitts Settlement Member at the base of the Salisbury Formation is placed at the first occurrence, in ascending the section, of reddish brown, fine- to medium-grained, feldspathic arenite with reddish brown mudstone intraclasts. Recessive beds of greyish green and reddish brown mudstone and shale are also present in the formation just above the base. The contact is not exposed. Other than the introduction of fairly minor reddish brown sandstones and mudstones, the Colpitts Settlement Member is dominated by coarse-grained, grey, feldspathic quartzose arenites and pebbly arenites similar to those in the underlying Cole Point Member of the Boss Point Formation. The disconformity in the section is inferred from palynological data. Spore locality 173 (Plate 4) has a specimen of *Savitrisporites majus* and of *Microreticulatisporites* aff. *nobilis*. Undoubted specimens of the latter spore first appear in the mid-Duckmantian (Dolby 1999b). Spore locality 174 (Plate 4) contains a specimen of *S. majus* and of *Florinites millotii*. The former is an essentially Bolsovian–Stephanian species, although it may range possibly down into the latest Duckmantian in Iowa (Dolby 1999b). The underlying samples (spore localities 175 and 176 on Plate 4) have an overall assemblage population that differs little from those in samples 173 and 174. Significantly, sample 176 contains *Protohaploxypinus* spp., a species that is unrecorded in the 130 Cumberland assemblages from the report area but is common in many Pictou assemblages. In contrast with the Salisbury samples, the samples in the underlying Cole Point Member of the Boss Point Formation (spore localities 140–145 on Plate 4) yield assemblages typical of the Westphalian A (Langsettian) (Dolby 1999b).

The Boss Point–Salisbury disconformity is also demonstrated in the Sackville Subbasin by a spore assemblage from Well 386 located 3 km southwest of the Highway 2–Walker Road intersection noted above. The assemblage (spore locality CQ on Plate 5) lies at a depth of 73 m in the Salisbury Formation, just above the contact with the Boss Point Formation. Dolby (1999b, p. 29–30) provides the following remarks on the assemblage: "…there are two groups of spores in the assemblage, one which is of late Duckmantian–?early Bolsovian age and the other of possibly Langsettian or older age. The latter has a darker preservation colour. The presence of *Endosporites globiformis* in significant numbers in the paler fraction indicates a late Duckmantian or younger age for the sample. Since this is a shallow well and there are no productive samples above this interval, the assemblage is considered to be in situ with a reworked, Langsettian component." Dolby's assessment suggests that the paler assemblage is dating the Salisbury Formation, and the darker fraction is eroded from the disconformably underlying Boss Point Formation.

The upper contact of the Salisbury with the Richibucto Formation is considered to be conformable. The contact is not exposed but was penetrated in Wells 399, 400, and 402. It is placed at the top of the highest quartzose sandstone of the Salisbury Formation, or at the base of the lowest red or grey, micaceous, lithic or arkosic channel sandstone of the Richibucto Formation. In many locations, the base of the overlying Richibucto Formation is defined by a major red or grey sandstone sequence. For instance, at the abandoned Pickard quarry in Sackville, the top of the Salisbury Formation is placed below the red sandstone (Plate 5), which is assigned to the Richibucto Formation. The light red sandstones in the Pickard quarry are comparable with those in the quarry at Wood Point 5 km south of Sackville. At both localities the sandstone beds contain coarse-grained detrital muscovite. The presence of coarse-grained muscovite is one of the lithological criteria used to assign rocks to the overlying Richibucto Formation (Johnson 1996).

Lateral Facies Relationships: Stratigraphic relationships and palynological data for the Salisbury Formation indicate that the grey Colpitts Settlement Member is laterally equivalent to red, fine-grained overbank sequences that occupy the base of the formation east of the Little River area.

The Colpitts Settlement Member at Little River is lithologically and temporally equivalent to the coal-bearing Minto Formation (Barss and Hacquebard 1967; Hacquebard 1972; Dolby 1998, 1999c).

Age: The Salisbury Formation has been dated as late Westphalian B (late Duckmantian) to Westphalian C (Bolsovian) on the basis of 24 age determinations on miospore assemblages (Table 4). Samples from several localities yield age-diagnostic species such as *Vestispora magna, V. pseudoreticulata, V. foveata, Illinites unicus*, and *Protohaploxypinus* spp. The youngest age assigned to the formation is early middle Westphalian C from locality CP on Little River (Dolby 1996b; Plate 4). Sample 172 slightly downsection is assigned an age no younger than early Westphalian C (Dolby 1996b). A Westphalian C–D age reported from a borehole sample assemblage (locality CM at Well 424 on Plate 3) in the Moncton area (by Barss *in* Carr 1968) was re-evaluated by Dolby (1995c) and assigned a late Westphalian B age. Lack of adequate stratigraphic control on spore samples hinders any attempt to assign an upper age limit to the formation. It is known within the limits of palynological zonation that the Salisbury Formation is at least as young as early Westphalian C and probably younger. A Stephanian age reported for the Salisbury Formation by Carr (1968) from spore locality CR at Shediac (Plate 3) is from the Richibucto Formation.

Depositional Environment: The paucity and limited thickness of sandstone intervals (channel and crevasse splay deposits) and the abundance of well-developed, silica-cemented paleosols in the red, fine-grained member suggest a well-drained environment, possibly on the distal part of an alluvial plain. That the formation is largely coeval with the sand-dominated Minto Formation (described later) could imply that the Salisbury largely represents an overbank succession associated with a major, laterally adjacent fluvial channel system. The multistoried grey channel sandstones at the base of the formation in the Little River area reflect that laterally coeval river environment.

Relationship to Previous Stratigraphy: The Salisbury Formation as defined herein is equivalent to the Salisbury and parts of the Richibucto and Boss Point formations as mapped by Gussow (1953). It is equivalent to only the lower part of the formation as defined by Carr (1968). The base of the revised Salisbury Formation corresponds approximately to the base of Cyclothem II of van de Poll (1970) in the Moncton Subbasin but is well below the base of van de Poll's Cyclothem II in the Sackville Subbasin. The formation is closely similar to the lower part of the Fundy Rose beds, an informal term used by Geosleuths Exploration Services (1995). On the basis of the presence of detrital muscovite in the upper part of the Fundy Rose beds, the sandstones in the Pickard and Wood Point quarries near Sackville are assigned herein to the Richibucto Formation.

Minto Formation

Authors: Muller (1951); revised by St. Peter (2000a).

Type Section: Muller (1951) named the formation after the community of Minto, which lies outside the report area along the border of Sunbury and Queens counties in central New Brunswick (Fig. 6). However, he did not specify a type section. Following Williams et al.

(1985), the type section is designated herein as the 75 m long exposure on the east side of Newcastle Creek (Fig. 76a, 76b) approximately 300 m downstream from the Park Street bridge in Minto (NTS 21 J/01).

Definition and Description: The name 'Minto Formation' was introduced by Muller (1951) for a sequence of buff to grey sandstones, pebbly sandstones, quartz-pebble conglomerates and minor grey siltstone, shale, and a thin but minable coal seam in the Minto and Chipman areas of central New Brunswick (Fig. 6). St. Peter (2000a) expanded the definition of the Minto Formation to incorporate the overlying Hurley Creek and Sunbury Creek formations as defined by Muller (1951), an expanded definition that is used herein. The Hurley Creek Formation as designated by Muller (1951) is a geographically restricted unit that lies above the Minto. In its absence beyond its depositional edge, it is not possible to differentiate the Minto from the overlying Sunbury Creek Formation. St. Peter (2000a) thus suggested the Hurley Creek be downgraded to a member and that the lithologically similar Sunbury Creek and Minto be amalgamated into a single Minto Formation. The late Westphalian B–C age for the entire succession in the Minto–Chipman area provides general support for this approach.

The Minto Formation consists predominantly of light-brown weathering, light grey, fine- to coarse-grained lithic, feldspathic, and quartzose, commonly plant-bearing sandstone; quartz-pebble conglomerate and intraclast pebble conglomerate; grey to reddish brown, ripple-laminated siltstone; and very fine-grained to fine-grained sandstone and reddish brown and dark grey siltstone and mudstone. The exposure at the type section is approximately 3 m thick and grades downward from grey, flaggy, feldspathic and lithic sandstone at the top (Fig. 76a) to grey pebbly sandstone at the base (Fig. 76b).

The lithotypes are commonly arranged into repeated fining-upward sequences. The exposures along Shaw Brook and Butler Creek in the McQuade Brook area (Fig. 10; Plate 3) comprise mainly intervals of reddish brown and lesser grey, fine- to medium-grained sandstones overlain by thick intervals of reddish brown and lesser grey siltstones and mudstones. The formation also includes mottled pink, reddish brown and greyish green, medium- to coarse-grained lithic sandstone and polymictic conglomerate; and reddish brown to purplish red and minor greyish red and buff siltstone to fine-grained sandstone. Minor coal seams are present in the formation. The Minto coal seam, which has an average thickness of only 30 cm to 90 cm, has been mined for more than 300 years (Smith 1989). Recent petrological studies on the Minto coal were conducted by Kalkreuth et al. (2000).

Thick siliceous paleosols occur locally at the base of the Minto Formation. The paleosols are mostly buff or cream to mottled buff and reddish brown and in most exposures display crudely developed prismatic jointing. The paleosols are locally so well developed that they resemble felsic volcanic rocks; however, rare floating quartz pebbles are locally preserved, attesting to their pedogenic origin (St. Peter 2000a; Johnson 2003b). A siliceous paleosol at the base of the Minto Formation on the northwestern side of the New Brunswick Platform near Stanley in central New Brunswick is purported to be up to 9 m thick (Sullivan 1981). Similar siliceous paleosols appear in the time-equivalent Salisbury Formation.

Distribution and Thickness: The Minto Formation is geographically restricted to the New Brunswick Platform, where it is widespread over most of the southwestern part of the platform in central New Brunswick (Fig. 6). In the report area, the formation appears along Shaw Brook

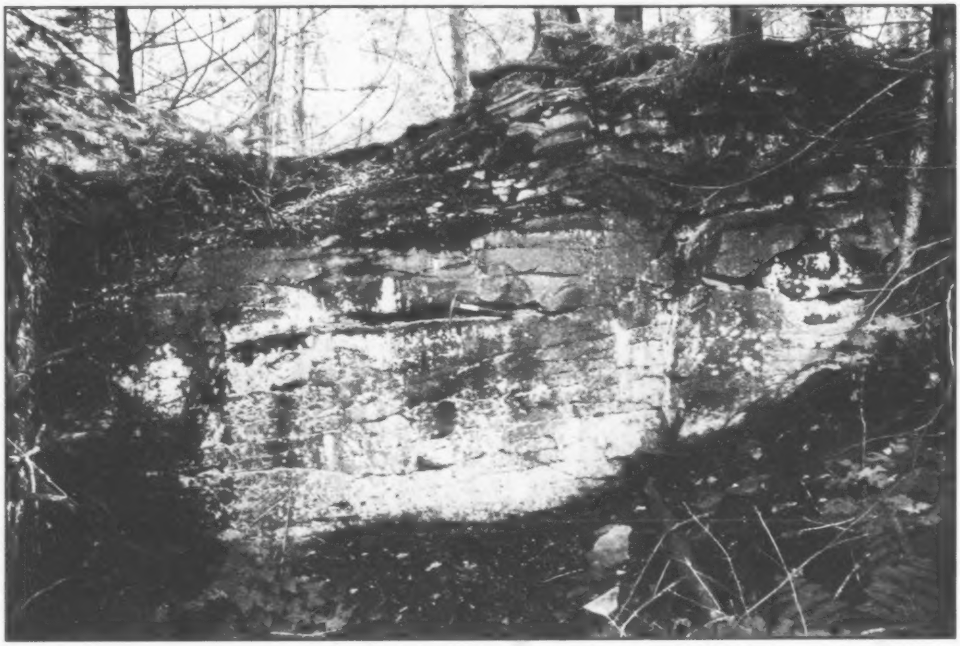


Figure 76a. Grey, flaggy feldspathic and lithic sandstone of the Minto Formation at its type section on Newcastle Creek in the community of Minto (Fig. 6). Hammer for scale.

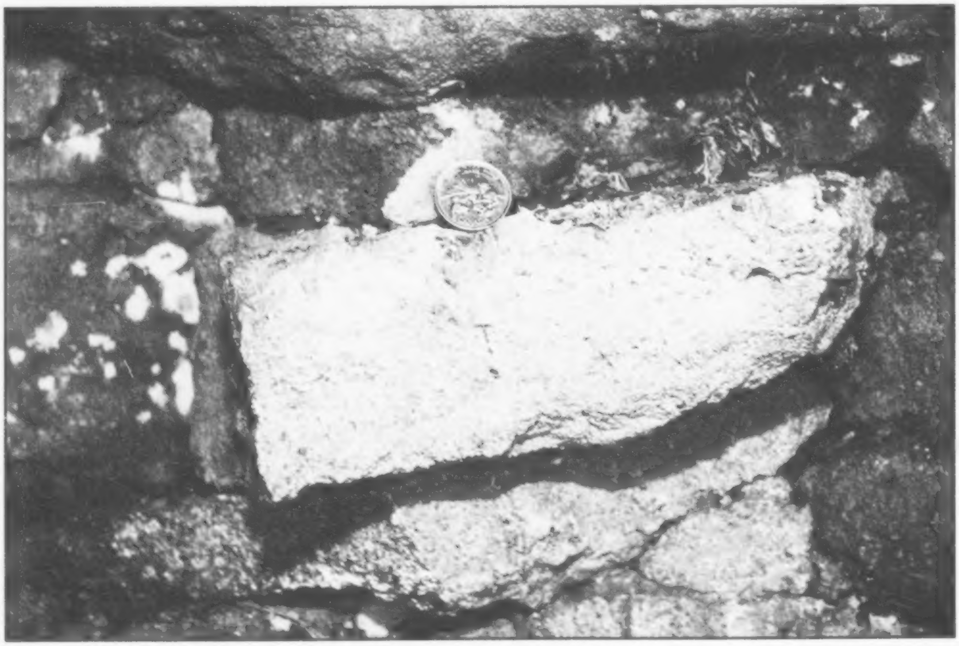


Figure 76b. Grey pebbly sandstone at the base of the Minto Formation at its type section, same location as Figure 76a. Coin = 2.3 cm.

and Butler Creek on the north side of the Indian Mountain Deformed Zone and is interpreted to underlie the area north of the Smith Creek Fault from near Highway 126 northeastward to McQuade Brook (Fig. 10). The formation in this area ranges in thickness from a few metres to tens of metres. Muller (1951) estimated a total thickness of 650 ft to 750 ft (200–230 m) for rocks now included in the Minto Formation.

Lower and Upper Boundaries: The Minto Formation disconformably to unconformably overlies the Early Carboniferous Hardwood Ridge Basalt and Newcastle Creek Formation of the Mabou Group. Where the Mabou is absent, the Minto unconformably overlies older Carboniferous strata as well as the pre-Carboniferous rocks that comprise the basement to the New Brunswick Platform. The contact with the overlying Richibucto Formation is considered gradational but has not been mapped in detail.

Lateral Facies Relationships: The Minto Formation on the New Brunswick Platform is stratigraphically equivalent to the Salisbury Formation of the Pictou Group in southeastern New Brunswick. The Minto Formation is also lithologically similar to and coeval with the South Bar Formation that comprises the lower part of the Morien Group in the Sydney Basin of Nova Scotia (Gibling 1995) and that hosts minor, subeconomic coals (Rust et al. 1987).

Depositional Environment: The repeated (stacked) fining-upward sequences of conglomerate–sandstone–siltstone–mudstone with local coal that characterize the Minto Formation are taken as evidence of fluvial and paludal deposition (e.g., see Miall 1992). Hacquebard and Barss (1970) and Kalkreuth et al. (2000) suggest that the Minto coal seam formed in a flat, fairly wide valley in which coal swamps were locally developed, although the abundance of sphenopsids such as *Calamites* sp. indicate a clastic-rich mire rather than a true coal swamp. The proposed depositional environment of the coal seam is an upper delta plain (Kalkreuth et al. 2000).

Age: Numerous spore assemblages obtained from the Minto Formation before 1981 (see Ball et al. 1981) and other assemblages collected later by one of us (CSP) and reported on in Dolby (1998, 1999c) indicate an age of late Westphalian B (late Duckmantian) to Westphalian C (Bolsonian). Palynological assemblages collected from the Minto coal seam by Kalkreuth et al. (2000) indicate an early Bolsovian (early Westphalian C) age, supporting early determinations from plants (Bell *in* Dyer 1926; Muller 1951).

Relationship to Previous Stratigraphy: Gesner (1841, p. 62–76) first described the coal and associated rocks in the Grand Lake area as part of his "great New Brunswick coal field." Robb (1850, p. 41–42) also referred briefly to the "coal measures" in this area. Rocks of the Minto Formation were called the 'Middle Carboniferous formation' by Bailey and Matthew (1873, p. 199–200), who divided the formation into lower "barren grey measures" and upper "productive coal measures." Bailey (1901) assigned these rocks to the Millstone Grit formation. Dyer (1926) included rocks of the Minto Formation in his Grand Lake Formation (now abandoned), which he divided into lower, middle, and upper members. The lower member corresponded to the "barren grey measures" of Bailey and Matthew (1873), but the middle member included redbeds that were not in the "productive coal measures." Muller (1951) introduced the name 'Minto Formation' and divided it into lower and upper members. The lower member is equivalent to Dyer's (1926) lower member, but the upper member encompasses only the lower part of Dyer's middle member. Muller (1951) assigned these rocks to the Pictou Group.

Ball et al. (1981) described the Minto Formation from boreholes drilled for the Carboniferous Drilling Project and intersected a highly indurated siliceous rock immediately below the formation in the Stanley area. They initially interpreted the siliceous unit as a reworked ash fall tuff, but Sullivan (1981) conducted a petrographic study and identified it as clastic sedimentary rock. The presence of the clay mineral dickite and a sutured texture led him to speculate that the rock had been hydrothermally altered, although the underlying and overlying rocks appeared unaffected. Poole (1957) contended that insufficient evidence existed to suggest a volcanic origin for this rock, yet Potter et al. (1979) described the unit on the bedrock geology map of New Brunswick as Mississippian silicic volcanic flows, tuffs, and related intrusive rocks.

Johnson (1996) reported the presence of a similar highly indurated siliceous interval in the Salisbury Formation, which is time-equivalent to the Minto Formation, and suggested it was a silica-cemented paleosol. St. Peter (2000a) and Johnson (2003b) mapped silica-cemented paleosols in basal Minto strata along the margin of the southwestern and southeastern New Brunswick Platform, respectively. Hacquebard and Barss (1970) and Kalkreuth et al. (2000) reported on the petrology and palynology of the Minto coal.

Richibucto Formation

Authors: Gussow (1953); revised by Carr (1968) and herein.

Type Section: Gussow (1953) named the formation for unspecified exposures near the community of Richibucto, which lies outside the report area in Kent County. A type section is designated herein as the coastal exposures along Northumberland Strait on the south side of Richibucto Harbour in Kent County, beginning 800 m south of the Richibucto Head lighthouse in Cap Lumière and extending for 300 m south to the intersection of the Cap Lumière Road with Highway 505 (NTS 21 I/10; Fig. 6, inset).

Reference Section: A reference section in the report area is designated as the coastal exposures in the low cliffs and intertidal zone along Northumberland Strait from Cap Pelé (NTS 21/01; Plate 2) to Murray Corner (NTS 11 L/04; Plate 1) in Westmorland County. Another suitable reference section is the core at depth interval 5.2 m to 167.6 m in Brunswick Mining and Smelting Corporation Ltd. diamond-drill hole CS-2 (Fig. 77; Brunswick Mining and Smelting Corporation Ltd. 1981). The hole was drilled near Melrose, Westmorland County (NTS 11L/04; Plate 1). Core for the hole is stored at the NBDNR repository in Sussex, New Brunswick.

Definition and Description: The Richibucto Formation as revised herein includes the beds in both the Richibucto and (abandoned) Scoudouc formations of Gussow (1953). As such, it comprises multistoried channel sequences of grey and lesser reddish brown and light red, thin-laminated to massive, parallel- and trough cross-bedded, micaceous, arkosic and lithic sandstone, pebbly sandstone, and mudstone-clast conglomerate (Fig. 78a, 78b).

The channel sequences are separated by intervals of dominantly reddish brown, very fine-grained to fine-grained, ripple-laminated to massive sandstone, siltstone, mudstone, and rare limestone. The sandstone–conglomerate cycles are multistoried, attaining thicknesses up to

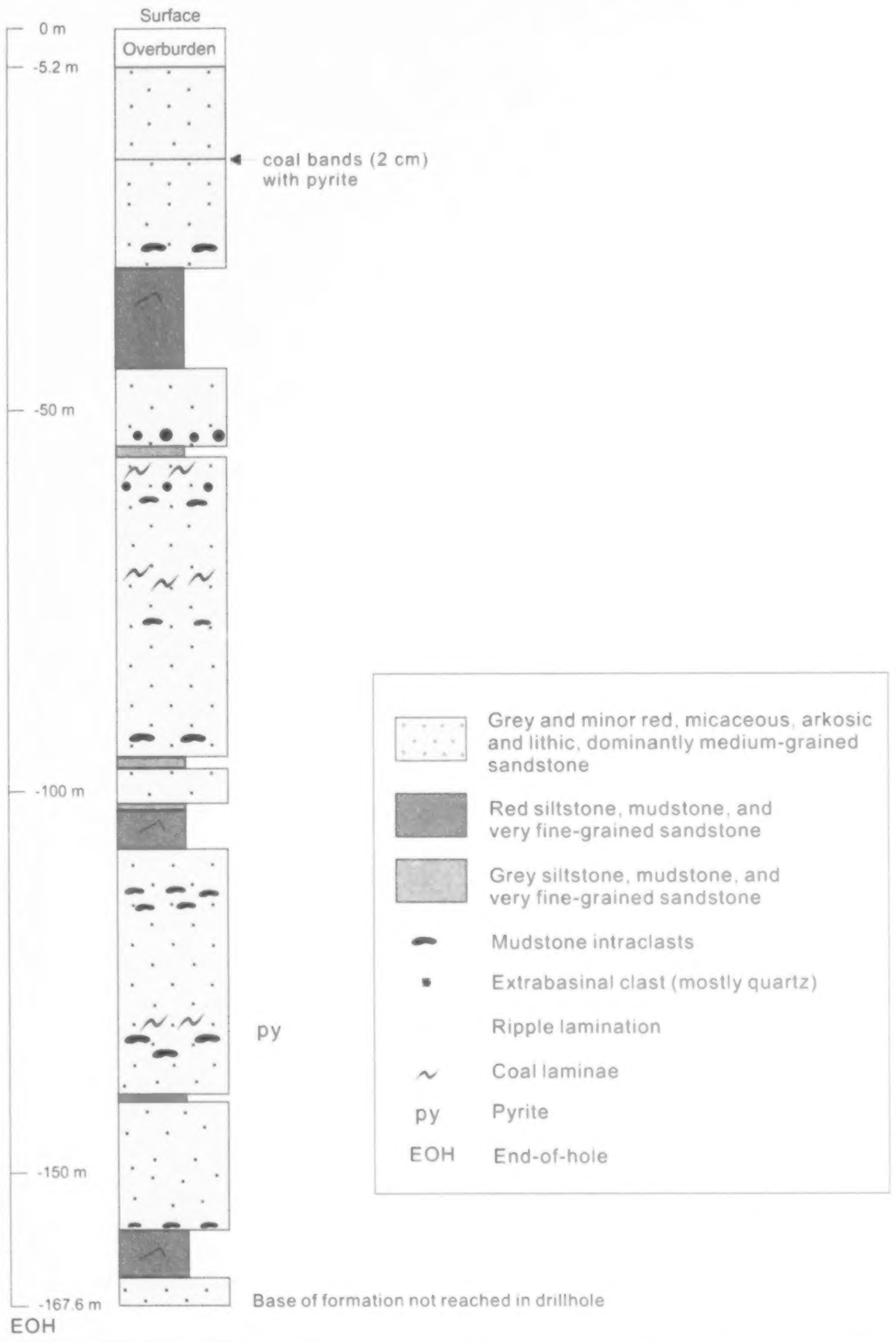

Surface
0 m
Overburden
-5.2 m
coal bands (2 cm)
with pyrite
-50 m
-100 m
py
-150 m
-167.6 m
EOH
Base of formation not reached in drillhole
Grey and minor red, micaceous, arkosic and lithic, dominantly medium-grained sandstone
Red siltstone, mudstone, and very fine-grained sandstone
Grey siltstone, mudstone, and very fine-grained sandstone
Mudstone intraclasts
Extrabasinal clast (mostly quartz)
Ripple lamination
Coal laminae
py Pyrite
EOH End-of-hole

Figure 77. Generalized stratigraphy of the reference section for the Richibucto Formation in Brunswick Mining and Smelting Corp. Ltd. diamond-drill hole CS-2 near Melrose, east of Port Elgin.

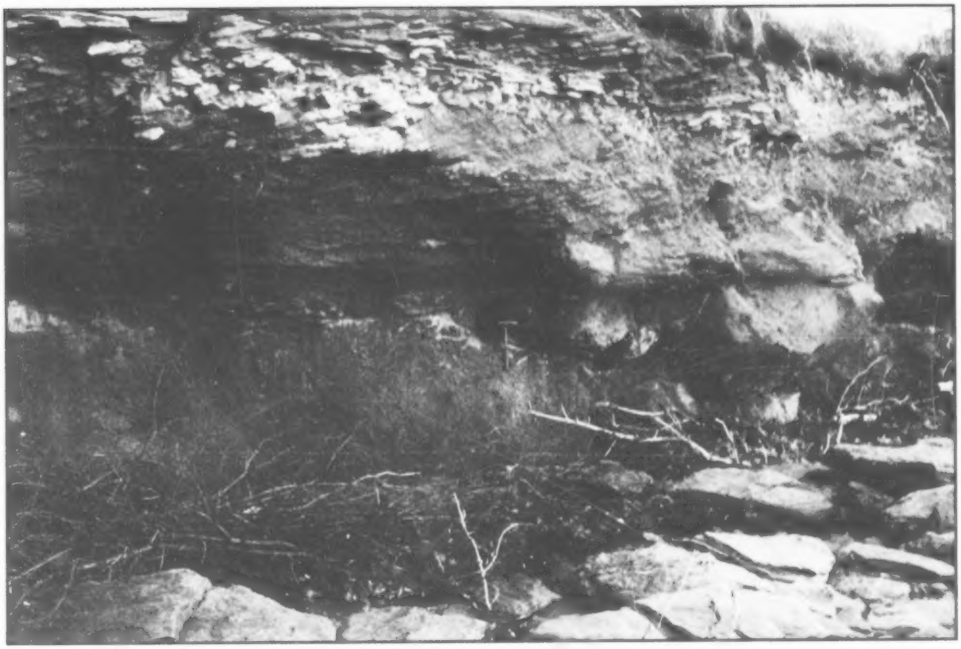


Figure 78a. Trough cross-bedded sandstone and channel lag conglomerate cutting into underlying overbank mudstones with reduced rooted top, Richibucto Formation, along the shoreline of Northumberland Strait near Cape Brulé east of Shediac.

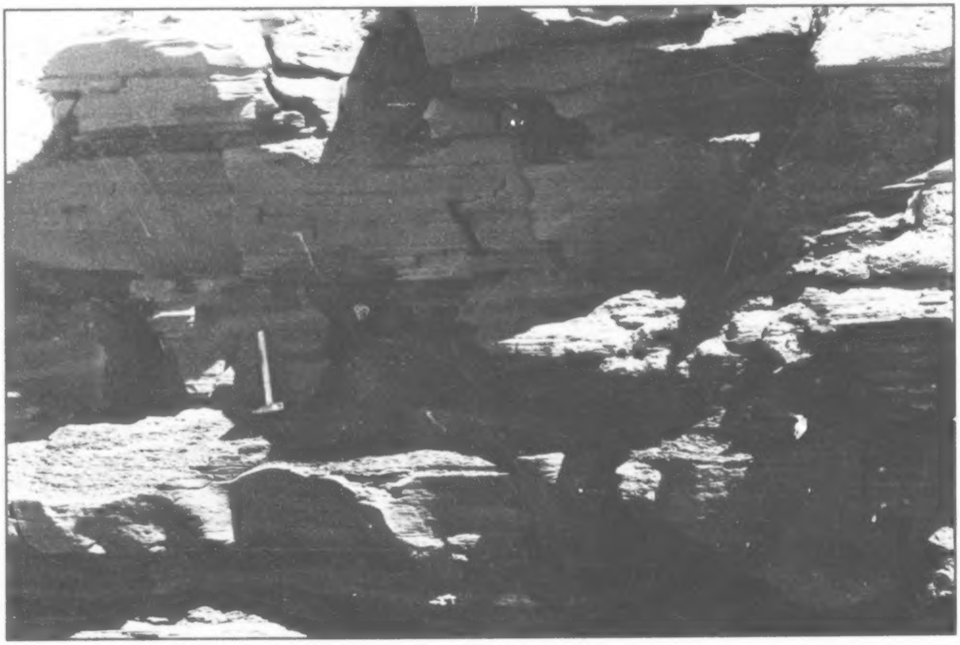


Figure 78b. Pale grey, parallel-bedded sandstone in the Richibucto Formation at Murray Beach Park along Northumberland Strait.

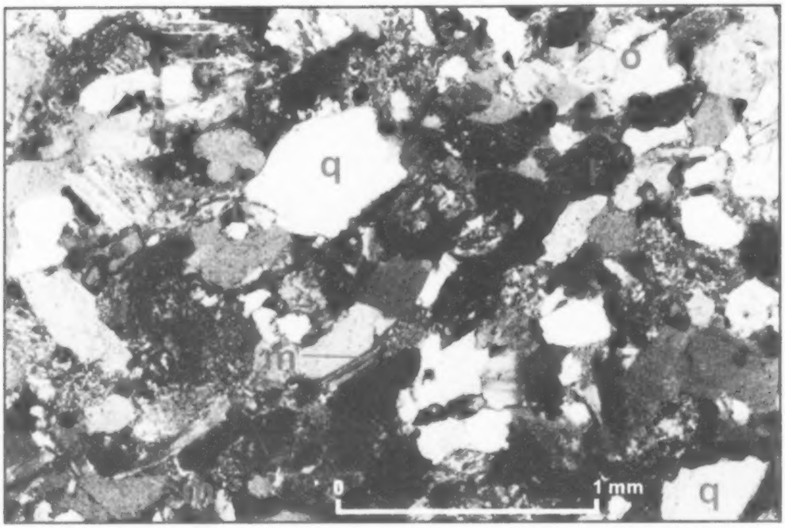


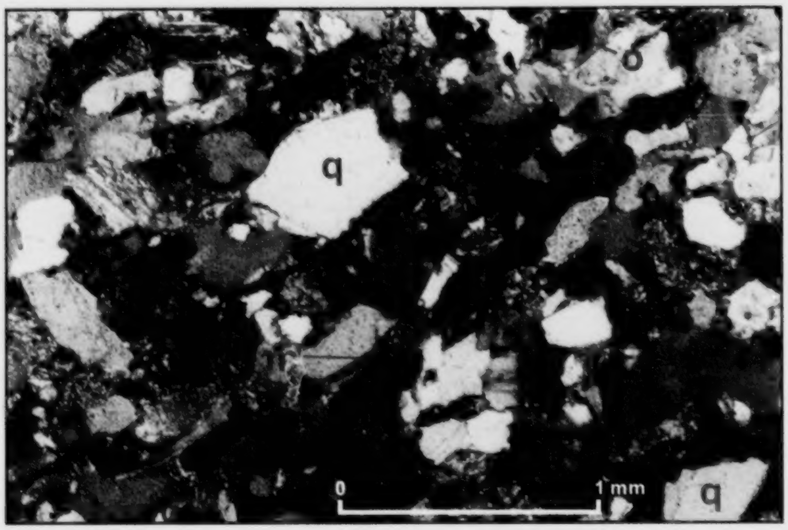
Figure 79. Photomicrograph of micaceous, feldspathic litharenite from the Richibucto Formation near Port Elgin. Note detrital grains of muscovite (**m**), feldspar (**f**), opaque iron oxides (**o**), lithic fragments (**l**), and quartz (**q**). Partly crossed nichols.

80 m. A fine-to-coarse ratio of approximately 0.5 was determined from 775 m of drill core from Brunswick Mining and Smelting holes in the Melrose area (Plate 1). Limited drilling northeast of Sackville indicates that the ratio of fine to coarse facies in that area is 1.3.

Medium- to coarse-grained channel sandstones in the Richibucto Formation have a wide range of compositions (Fig. 73b). Feldspathic litharenite from the Port Elgin area shows abundant coarse-grained detrital muscovite, a common feature in the sandstones (Fig. 79). Kaolinized feldspars give the weathered rock a chalky appearance. The sand-dominated sequences are typically trough cross-bedded and alternate with massive and thin-laminated, parallel-bedded sandstones, the latter having been quarried for building stone in the past (Martin 1990). The thin-laminated, cross-bedded sandstones exhibit broad, low-amplitude troughs. Irregular-shaped calcareous sandstone concretions similar to those in the overlying Tormentine Formation are common.

A thin (4 cm) coal bed with an underclay of grey shale occurs in thick channel sandstones in the Smith Cut Stone and Quarries Ltd. pit at Shediac (Plate 3). Well-rounded, extrabasinal, granule-size quartz and lithic clasts occur locally in the sandstones. Coalified plants and logs are abundant within the channel sandstoneconglomerate sequences (Fig. 80). Calcareous, mudstone-chip conglomerates (lag deposits) are ubiquitous at the base of the channel sequences.

A 30 cm thick bed of conglomerate carrying limestone pebbles and cobbles appears in the section between Cap Pelé and Petit Cap on the shore of the Northumberland Strait. Limestone clasts from a similar conglomerate exposed farther east on the shore near Murray Corner were examined by Peter von Bitter at the Royal Ontario Museum and determined to be of lacustrine origin (P. von Bitter, written comm. to SCJ, 1995). The source of the limestone clasts is likely intraformational, as a laterally extensive bed of parallel-laminated limestone greater than 30 cm in thickness lies within sandstones along the shore at Petit Cap.



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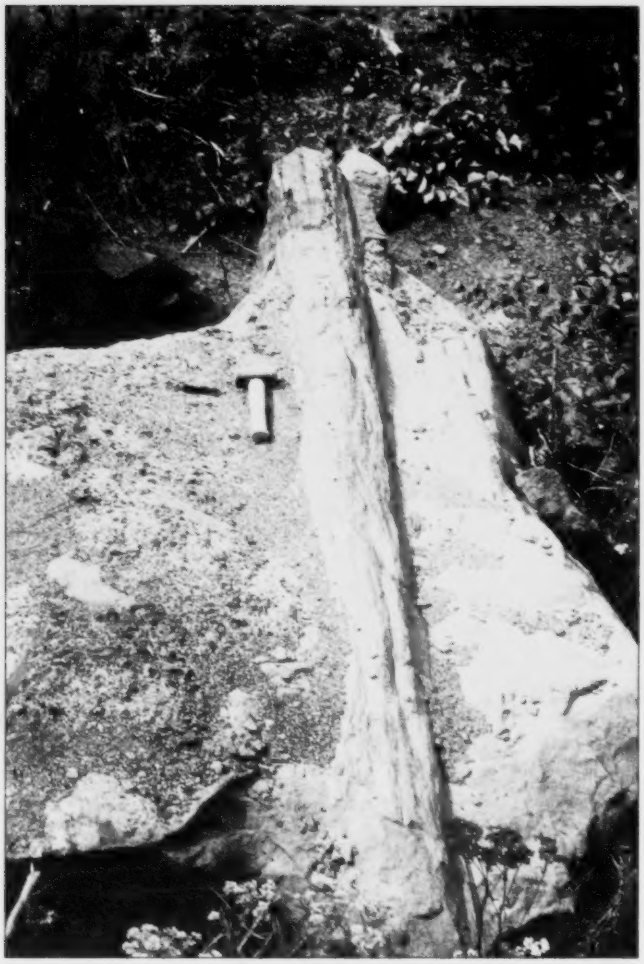


Figure 80. Fossil tree lying on bedding plane in grey sandstone of the Richibucto Formation in an abandoned quarry off Highway 16 west of Cape Tormentine.

The fine-grained rocks of the Richibucto Formation are overwhelmingly red with shades ranging from brick red to reddish brown to brownish grey. True grey (not reduced) mudstones are sparingly present, although grey mudstone comprises the dominant clasts within intraformational conglomerates. Brownish grey, very fine-grained to fine-grained, ripple-laminated sandstone with well-developed rib-and-furrow structures is an abundant lithology in the fine-grained facies. The overbank facies commonly exhibit oval-shaped soil peds, waxy hematite-lined cutans, and reduced rooted zones at the top of the mudstone sequences. These attributes are interpreted to be features of vertisols (Retallack 1988; Mack et al. 1993). 'Bull's eye'-type reduction spheroids are also common in the red mudstones. Along Gaspereau River (Plate 2), thin coal seams with underclays of grey shale are exposed. Isolated exposures below and above the coal seams are dominantly red shale and siltstone, suggesting that the coals lie within thick overbank sequences in this area. Sand bodies commonly incise the reduced tops of mudstone sequences in the Richibucto Formation (Fig. 78a). Gussow (1953) misinterpreted one such erosive contact as an "obvious disconformity" between his Richibucto and Scoudouc formations.

Distribution and Thickness: In the report area, the formation crops out along the shore of Northumberland Strait from Cape Brulé to Peacock Point and on the shore of Baie Verte in the Port Elgin area. It is less well exposed inland but is widely distributed, extending east from Moncton to Baie Verte and southwest to the Sackville area. The formation is also exposed at Wood Point on the south side of the Wood Creek Fault (Fig. 65) and is interpreted to lie on the south side of the Wood Creek Fault near the mouth of Missaguash River (Plate 5). Richibucto beds overlie the Minto Formation along Cocagne River in the northwestern part of the report area (Plate 3).

Due to the flat-lying nature of the beds, the most reliable thickness estimates for the formation come from drillhole data. A total thickness is unknown, as no holes penetrate the entire formation, but a thickness of 265 m was intersected in Well 400 near Port Elgin. Gussow (1953) estimated the unit to be around 300 m thick on the basis of a section constructed along the axis of the Westmorland Anticline (Plates 1, 2).

Lower and Upper Boundaries: Neither the lower nor upper contact of the Richibucto Formation is exposed. The lower boundary is interpreted to be conformable and is described earlier under ***Salisbury Formation***. The contact of the Richibucto Formation with the overlying Tormentine Formation is considered to be gradational and conformable. It is placed at the top of the highest exposed grey bed, above which the sequence becomes dominantly red. In the absence of any colour difference, the two formations are lithologically very similar.

Lateral Facies Relationships: Gussow (1953) differentiated an upper unit of grey, multistoried sandstone with associated minor grey mudstone (his Richibucto Formation) from an underlying unit of reddish brown, fine-grained sandstone, siltstone, and mudstone and associated brown arkosic sandstone (his Scoudouc Formation). Carr (1968) subsequently abandoned the Scoudouc Formation by reassigning all grey arkosic sandstone to the Richibucto Formation and all reddish brown, fine-grained sandstone, siltstone, and mudstone to the underlying Salisbury Formation. Johnson (1995, 1996) went one step further and suggested that the entire Scoudouc Formation, including the redbeds, was part of the Richibucto Formation.

Mapping the nearly continuous exposure along 50 km of Northumberland Strait coastline and relogging more than 1000 m of drill core demonstrate that the redbeds do not exclusively lie below the arkosic sandstone, as Gussow (1953) and Carr (1968) envisioned. Together, they comprise repetitive cycles of grey to brown arkosic sandstone and very fine-grained to fine-grained red sandstone, siltstone, and mudstone. The outcrop pattern in the Port Elgin area supports this interpretation, as the Scoudouc Formation of Gussow 1953 typically occurs as 'inliers' within the Richibucto Formation (see Johnson 1995, her Fig. 5, units 4a, 4b), indicating a close spatial relationship between the two lithofacies. Gussow (1953, p. 100) speculated that the Scoudouc Formation was probably equivalent to the Richibucto Formation but did not have the evidence needed to confirm the correlation.

As noted earlier (see ***Pictou Group***), a strong argument can be made that the Richibucto Formation is equivalent to the Malagash Formation in its type area (the Pictou grey beds of Bell 1926, 1944). (Strata in the core of the Athol Syncline of Nova Scotia, mapped originally as Cumberland Group (Bell 1944) and later as Malagash Formation (Ryan and Boehner

1994), are excluded here from correlation with the Richibucto Formation.) The Richibucto and Malagash formations possess many lithological similarities. Both consist of multistoried and multilateral grey and minor red arkosic or lithic sandstone, dominantly red mudstone, laterally persistent lacustrine limestones, and thin coal seams; such characteristics establish their similarity in provenance and depositional setting. The stacked conglomerate–sandstone sequences in the Richibucto Formation are about twice as thick as the intervening mudstone — again, similar to the Malagash Formation. The two formations also share a peculiar feature in the presence and character of intraformational conglomerates. The intraclasts in the conglomerate are mainly grey mudstone, yet the overbank deposits in both formations are overwhelmingly red. The Richibucto Formation may also be equivalent to part of the Balfron Formation, which is characterized by multistoried arkosic sandstone, mudclast conglomerate, and laterally extensive lacustrine limestone (see Ryan and Boehner 1994, their Fig. 2-22). Moreover, limited lateral variability in facies is characteristic of all three formations.

A lithological correlation between the Richibucto and Malagash formations, and probably the Balfron Formation as well, is supported by miospore data. Palynomorphs in the type area of the Malagash Formation at Malagash Point and nearby Cape Cliff date these strata as young as Westphalian D to Stephanian (Fig. 56), essentially the same age as the late Westphalian D to Stephanian Balfron Formation (Dolby *in* Ryan and Boehner 1994). Other spore ages given for the Malagash Formation (outside the Athol Syncline) are no older than late Westphalian C and as young as Stephanian, or are non-specific late Westphalian (Dolby *in* Ryan and Boehner 1994). A similar age for the Richibucto Formation (see ***Age***, below) suggests a temporal equivalency among the Richibucto, Malagash, and Balfron formations. In contrast, strata mapped as Malagash Formation in the core of the Athol Syncline are older. They are likely lithologically and temporally equivalent to grey sandstones of the Salisbury and Minto formations, which define the base of the Pictou Group in New Brunswick (Barss and Hacquebard 1967; Hacquebard and Barss 1970). Strata in the Athol Syncline core are more akin to the Spicers Cove Member (Westphalian B to early Westphalian C) of the upper Ragged Reef Formation of the Joggins section.

Age: Spore assemblages from the Richibucto Formation (Table 3) are definitely no older than middle Westphalian C (middle Bolsovian) and no younger than Stephanian C (Gzhelian) (Fig. 9, 56). The greater part of the formation yields spores of Westphalian D age (Dolby 1995c, 1996b). Samples from near the base of the formation in a quarry at Berry Mills (spore locality CW on Plate 3) have been assigned an age of no older than early middle Westphalian C (Dolby 1999b). A sample slightly higher in the section from a quarry in the Moncton area (spore locality 180 on Plate 3) is no older than Westphalian D (Dolby 1996b). An assemblage at locality CT (Plate 3) on Scoudouc River near the base of the formation has been assigned an age of no older than middle to late Westphalian D on the basis of the presence of *Vestispora witneyensis*. Upsection of locality CT, mainly late Westphalian D and early Stephanian (Cantabrian) ages are indicated by spore assemblages in the Shediac area (spore localities 178, CR, CS on Plate 3). The post-Westphalian ages are assigned on the basis of extremely abundant striate bisaccate pollen and *Potonieisporites* spp. Specimens of *Granulatisporites elegans* from a sample on Shediac River (locality 177 on Plate 3) may be as young as Stephanian C (late Gzhelian; Dolby 1996b). Such a young age is significant, given that Wagner and Lyons (1995) identified a stratigraphic break between the Cantabrian (Kasimovian) and Stephanian C (early Gzhelian: see Heckel and Clayton 2006) throughout the Appalachians (Fig. 9). At the present level of understanding, however, there is no known lithological basis for a break within the Richibucto Formation.

Depositional Environment: Ryan and Boehner (1994) propose a sandy braided-stream facies and a 'composite stream' model to explain the style of deposits in the laterally coeval Malagash and Balfron formations, respectively, in Nova Scotia. The Richibucto Formation demonstrates many features in common with meandering stream deposits, including fining-upward cycles of conglomerate, sandstone, and mudrocks, and the concomitant upward-decreasing scale of sedimentary structures. However, the multistoried sand sequences (up to 80 m thick) are inconsistent with the commonly conceived model of meandering stream deposits. On the other hand, such sequences are consistent with braided or anastomosing stream models.

The composite stream model (Ryan and Boehner 1994, their Fig. 4-33) envisages low-gradient, anastomosed channel geometry with accompanying levees, and laterally equivalent crevasse splays and interchannel swamps, the last-named giving rise to thin coal seams. The channel morphology could explain the multistoried and multilateral geometry of the sandstone sequences. However, the Richibucto, Malagash, and Balfron formations may represent a transition, both upward and laterally, from a braided to a meandering stream system. The local presence of thin-laminated limestone beds within sandstones of the Richibucto Formation implies the abandonment of channels and their occupation by ponded water. Thin coal seams associated with channel sandstones also suggest the abandonment of channels that were subsequently occupied by marsh or swamp vegetation.

Relationship to Previous Stratigraphy: The Richibucto Formation as defined herein is equivalent to most of the Scoudouc Formation and the entire Richibucto Formation as defined by Gussow (1953) and to parts of both Cyclothem II and Cyclothem III of van de Poll (1970).

Tormentine Formation

Authors: Gussow (1953); revised herein.

Type Section: The formation was named for the flat-lying beds along the shoreline at Cape Tormentine on Northumberland Strait. The type section is designated herein specifically as exposures along the shore of Cape Tormentine from Bayfield southward to Indian Point in Westmorland County (NTS 11/L04; Plate 1).

Definition and Description: The name 'Tormentine Formation' was introduced by Gussow (1953) and is used herein to describe red sandstone and mudstone overlying the dominantly grey beds of the Richibucto Formation. The status of the Tormentine as a separate formation based on lithostratigraphic criteria is debatable, although the Tormentine Formation appears somewhat finer grained than the Richibucto Formation in some coastal exposures. The Tormentine comprises red and brownish to greyish red sandstone, pebbly sandstone, and intraformational conglomerate; and brick red to reddish brown siltstone and mudstone. Borehole logs indicate that the sandstone–conglomerate cycles can attain thicknesses of up to 35 m; the intervening siltstone–mudstone cycles are typically 5 m to 15 m thick (Fig. 81).

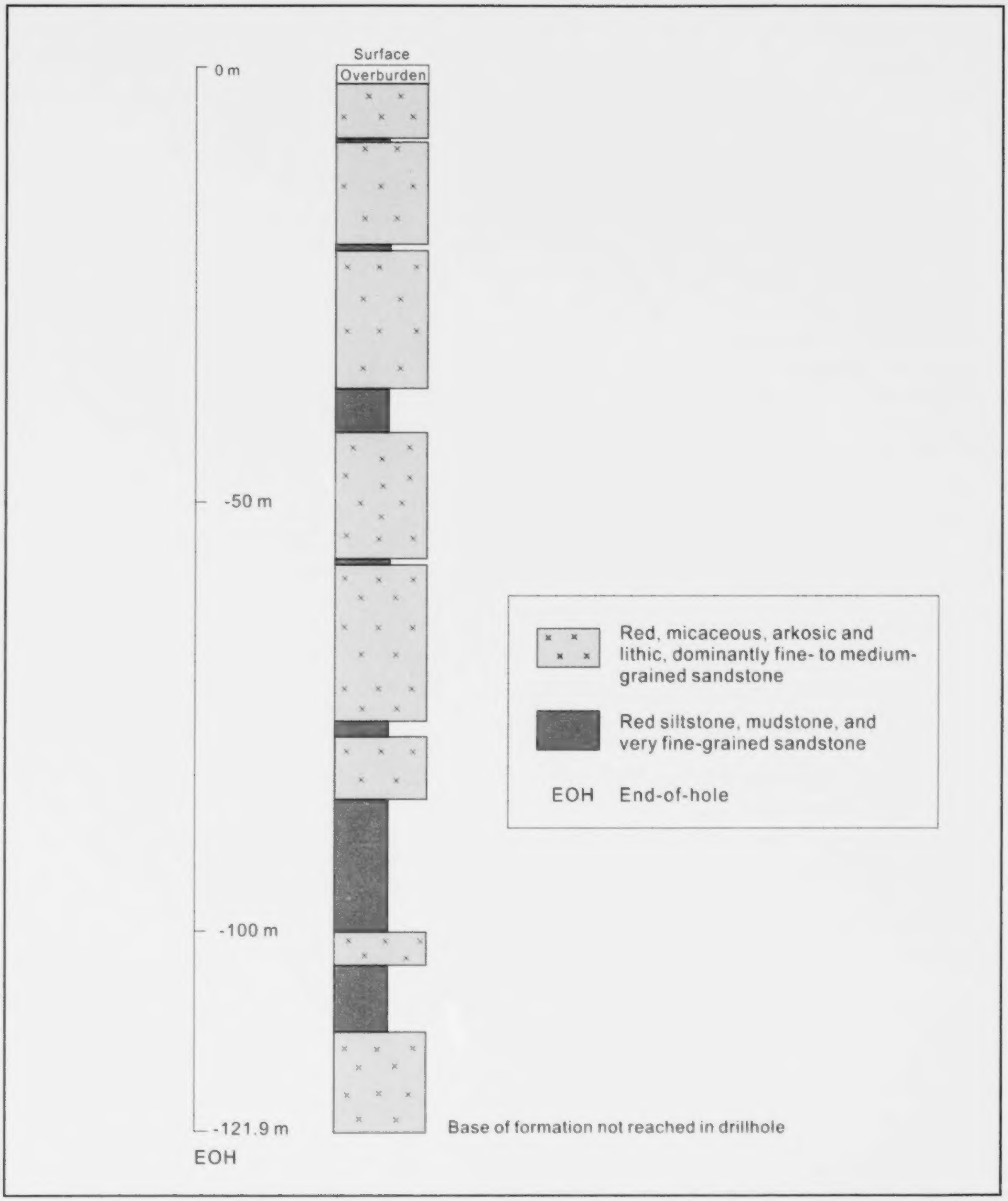

Surface
Overburden
0 m
-50 m
-100 m
-121.9 m
EOH
Red, micaceous, arkosic and lithic, dominantly fine- to medium-grained sandstone
Red siltstone, mudstone, and very fine-grained sandstone
EOH End-of-hole
Base of formation not reached in drillhole

Figure 81. Generalized stratigraphy of the Tormentine Formation near Upper Cape, adapted from the litholog for Carboniferous Drilling Project Borehole 210 (Well 003). See Appendix 1 for details.

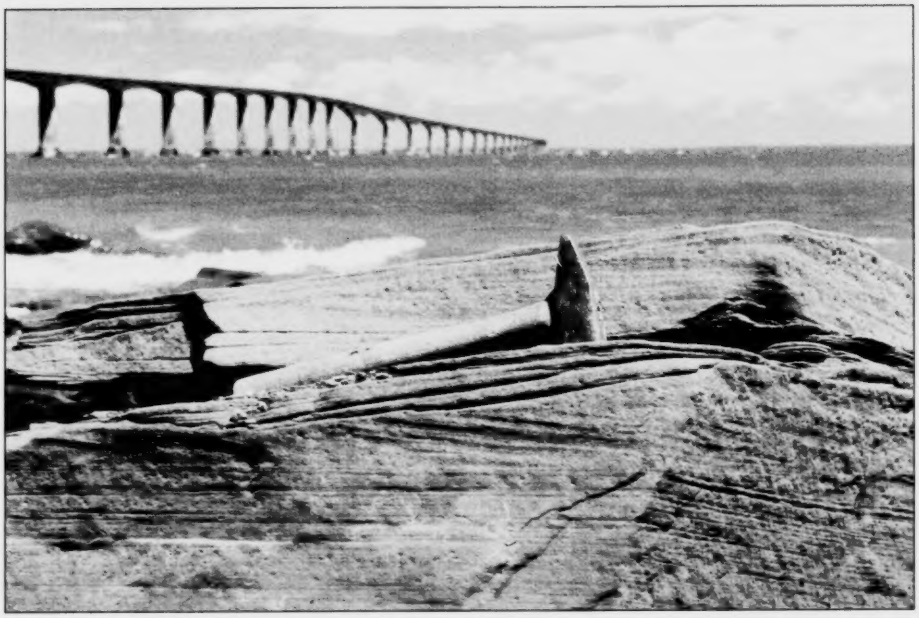


Figure 82. Trough cross-bedding in red sandstone of the Tormentine Formation at Cape Jourimain on Northumberland Strait.

Lenses of calcareous mudstone-clast conglomerates up to 2 m thick are common at the base of channel sequences. The channel-lag conglomerates contain intraclasts of red mudstone and invariably have a calcareous sandy matrix. Medium- to coarse-grained sandstones are commonly trough cross bedded (Fig. 82) and more rarely are parallel bedded or flat bedded. In many exposures, the sandstones are poorly indurated. As with the Richibucto Formation, trough cross-beds typically have low width-to-thickness ratios.

Calcareous sand concretions are ubiquitous within the sandstones. Spherical, tiered, and dumbbell shapes are present in the low coastal cliffs immediately west of the abandoned ferry terminal. Irregular, elongate calcareous bodies associated with carbonate-replaced plant stems also appear in the channel sequences. Rare dewatering features such as ball-and-pillow structures up to 15 cm thick occur locally. Ripple cross-laminations are common in very fine-grained to fine-grained sandstone and siltstone. Green reduction spheroids and blocky soil peds typical of vertisols are common in the overbank sequences.

The medium-grained, trough cross-bedded sandstone is characterized by abundant coarse-grained muscovite (up to 8%) and minor biotite. The sandstones are submature to immature with compositions ranging from feldspathic litharenite to lithic arkose (Fig. 73c, 83).

Distribution and Thickness: The formation is exposed in low cliffs and the intertidal zone along the shores of Northumberland Strait and Baie Verte in a narrow arcuate belt 2.5 km wide that represents the easternmost outcrops of the Westmorland Anticline (Plate 1). As with the underlying Richibucto Formation, a reliable thickness estimate is difficult to determine due to the extremely low angle of dip. The unit is continuously exposed for 40 m in the Indian Point area. As well, 120 m of the formation was intersected in Well 003 (Fig. 81) near Upper Cape (Ball et al. 1981). Gussow (1953) estimated that the onland part of the formation is about 150 m thick.

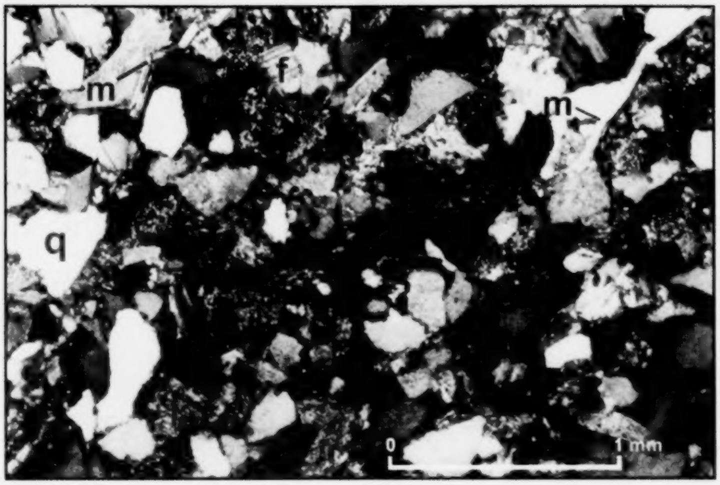


Figure 83. Photomicrograph of lithic arkose from the Tormentine Formation at Indian Point near Cape Tormentine. Note coarse muscovite (**m**), feldspar (**f**), quartz (**q**), and lithic fragments (**l**). Partly crossed nichols.

Lower and Upper Boundaries: The lower contact of the Tormentine Formation is not exposed but, as described earlier (under ***Richibucto Formation***), its boundary with the underlying Richibucto Formation has been placed historically at the grey to red colour transition. In the absence of any colour difference, there is little in the way of field criteria to distinguish between the Tormentine and Richibucto formations. The Tormentine Formation is the youngest unit of the Pictou Group in the report area.

Lateral Facies Relationships: The Tormentine Formation is coeval with and lithologically similar to the Tatamagouche Formation in Nova Scotia (Ryan and Boehner 1994).

Age: No grey mudrocks or coal seams that could possibly yield spores have been observed in the Tormentine Formation. On the basis of its stratigraphic position above the Richibucto Formation, the Tormentine is dated at probably Stephanian or younger (Fig. 9, 56).

Depositional Environment: The fining-upward sequences, bedforms, and thickness of the conglomerate–sandstone channel intervals in this formation are similar to those of the Richibucto Formation. Accordingly, the depositional environment is interpreted to be analogous to the low-gradient composite stream system suggested for the Richibucto Formation in New Brunswick and for the upper Pictou Group in Nova Scotia (Ryan and Boehner 1994).

Relationship to Previous Stratigraphy: The Tormentine Formation as currently mapped is unchanged from Gussow (1953). Van de Poll (1970) considered rocks assigned to the Tormentine Formation to be part of his Cyclothem III. Ball et al. (1981) included the Tormentine Formation in their undivided Pictou Group.

FUNDY GROUP

The Mesozoic continental rocks of the Fundy Group are not an objective of study by the authors and consequently are given only cursory treatment here. The Fundy Group was named and described by Klein (1962) to identify the bright red, terrestrial clastic strata and associated tholeiitic basalt along the south shore of the Bay of Fundy in Nova Scotia and locally along the north shore of the bay in New Brunswick. Most of the group lies below the waters of the Bay of Fundy.

On the north side of the bay, the group is greater than 3.6 km thick, as indicated by a gas and oil well put down in 1975 about 10 km east of The Wolves (Islands) by a consortium led by Mobil Oil Canada Limited. The base of the Fundy Group was not reached in that well, but the section there is divisible into four formations that correlate with surface formations in Nova Scotia. From the bottom of the well upward, they are the 1) Wolfville Formation (red arkose, subarkose, and orthoquartzite, with minor pebble to cobble conglomerate and rare mudrocks), 2) Blomidon Formation (red shale and siltstone), 3) North Mountain Basalt (massive and amygdaloidal basalt, and minor red clastic interbeds between flows in the upper part of the formation), and 4) Scots Bay Formation (interbedded sandstone, limestone, and shale).

In the report area, rocks of the Fundy Group appear on land in only two locales: along the north shore of Rocher Bay at Dennis Beach, and east of there at Red Head in the Waterside area (Fig. 8; Plate 6). The outcrop at Dennis Beach comprises red, coarse-grained to granular, trough and planar cross-bedded arkose, red quartz-pebble conglomerate, and rare lenticular beds of bright red mudstone. Most of the quartz pebbles are white, well rounded, and show high sphericity. The matrix of the conglomerate is clean arenite composed mainly of coarse-grained feldspar and quartz. The exposures at Red Head were not visited but are presumably similar to those at Dennis Beach.

The contact of the Fundy Group with the adjacent bounding strata of the Mabou and Cumberland groups is not exposed in the Waterside area but is interpreted to be defined by faults on the west, north, and east sides (Fig. 8; Plate 6). An east–west-striking fault is interpreted to bound the north side of the unit, as evidenced by the following: 1) the beds at Red Head and Waterside strike northeast into the closely adjacent exposures of the Shepody Formation, and 2) the outcrop at Dennis Beach reveals a minor fault with a strike of 100°, a dip of 70°S, and slickensides implying down-to-the-south, dip-slip displacement. The fault contacts and limited exposure of the Fundy unit at Waterside preclude any thickness estimate. The dipping beds at Red Head suggest that several tens of metres of section are present there.

The generally coarse-grained character of the Waterside beds indicates that the formation there may be correlated more appropriately with the Fundy Group as defined on the north side of the basin in New Brunswick rather than with the beds in Nova Scotia. For example, the Fundy Group in the St. Martins area 60 km southwest of Waterside has been subdivided into three formations, all coarse grained. Where the group has been examined in greatest detail there, it comprises (from the base up) the Honeycomb Point, Quaco, and Echo Cove formations (Klein 1962; Nadon 1981; Nadon and Middleton 1984). The Honeycomb Point Formation includes alluvial-fan conglomerates and well-sorted, medium-grained, quartzose sandstone with large-scale cross-beds and pebble conglomerate. The Quaco Formation contains red to greyish red, cobble to boulder roundstone conglomerate with abundant quartz clasts, and medium- to coarse-grained sandstone and pebble conglomerate. The Echo Cove Formation comprises red to greyish red, medium- to coarse-grained, cross-bedded sandstone, pebble sandstone, roundstone conglomerate, intraformational conglomerate, breccia, and minor mudstone. Each of the formations is several hundred metres thick, and the preserved part of the Fundy Group around St. Martins has an aggregate thickness in the order of 2 km.

It is not possible to assign or correlate the Fundy beds at Waterside with one of the formations as represented in the St. Martins area, as too little section is preserved around Waterside to speculate where it may lie stratigraphically relative to the more westerly beds. No plant fossils or spores have been retrieved from the Waterside strata. Flora from the Echo Cove Formation are Late Triassic (Holden 1913), whereas miospores from the formation indicate a middle to early Late Triassic (Ladinian–Carnian) age (Nadon 1981; Nadon and Middleton 1984).

SUMMARY OF STRATIGRAPHY

Horton Group

The oldest or basal depositional sequence in the Maritimes Basin of southeastern New Brunswick is the Horton Group. It comprises the historically defined Memramcook Formation and overlying Albert Formation (Norman 1941a; Gussow 1953). The Memramcook Formation of Norman (1941a, 1941b), Gussow (1953), and McLeod and Ruitenberg (1978) is subdivided into a basal coarse redbed sequence for which the name 'Memramcook Formation' is retained. Fine-grained redbeds that lie above the coarse strata are designated as the McQuade Brook Formation (St. Peter 2006a). The definition of the Albert Formation is restricted from that of previous workers. It comprises grey fluvial conglomerates and sandstones and lacustrine shales and oil shales, but not the laterally equivalent and overlying coarse redbeds that lie on the southern shoulder of the Westmorland Uplift. Those beds are separated from the Albert Formation and are herein newly named 'Steeves Mills Formation.' Additional deletions from the Albert Formation are noted below under the Sussex Group. The uppermost unit of the Horton Group in the Cocagne Subbasin is the Indian Mountain Formation (St. Peter 2006a), a unit of mainly red terrestrial mudstones and sandstones conformably overlying the lacustrine Albert Formation.

The Horton Group ranges in age from Late Devonian (Famennian) to Early Carboniferous (early to middle Tournaisian).

Sussex Group

In the eastern Moncton Subbasin, the Sussex Group lies unconformably on the Horton Group and overlaps onto crystalline rocks of the Caledonia Uplift. The depositional contact with the crystalline rocks was noted by McLeod (1980, p. 7). The group comprises proximal polymictic conglomerates and sandstones of the Round Hill Formation, formerly of the Albert Formation (McLeod 1980), distal grey mudrocks and playa evaporites (rock salt and glauberite) of the Gautreau Formation (Norman 1932; Greiner 1962), and overlying alluvial–fluvial red mudrocks of the Weldon Formation (Norman 1941a). Norman (1941a), Gussow (1953), Carr (1968), McLeod (1980), Carter (1985), Carter and Pickerill (1985b), and St. Peter (1992, 1993) all assigned the strata here allocated to the Gautreau Formation to the Albert Formation. A thin felsic ash bed, the Boyd Creek Tuff, occurs in the lower part of the Weldon Formation (St. Peter 1989b, 1992).

In the southern part of the Indian Mountain Deformed Zone, which represents a northern exhumed part of the Westmorland Uplift, the Sussex Group lies unconformably on basement rocks and erosional outliers of the Horton Group (Memramcook Formation). There, the Sussex Group comprises two proximal, conglomerate-dominated units: the basal Stilesville Formation and the upper Briggs Cross Formation (St. Peter 2006a; Park and St. Peter 2009).

The two coarse formations are separated by grey and red mudrocks and minor sandstones of the 'distal' Gautreau and Weldon formations. In the Cocagne Subbasin, coarse-grained terrestrial strata of the Sussex Group (Ridge Brook Formation) unconformably overlie the Horton Group. Distinctive clast content in the Ridge Brook implies a source area north of the basin-bounding Belleisle Fault.

Palynomorph assemblages provide a latest middle to late Tournaisian (Zones 3B–5; Fig. 15) age for formations of the Sussex Group.

Windsor Group

The Windsor Group lies unconformably on the Horton and Sussex groups and locally oversteps them onto bounding crystalline uplifts. In the report area, rocks of the Windsor Group are restricted to south of the Westmorland Uplift. The basal unit of the group is a coarse continental redbed sequence, the Hillsborough Formation (Norman 1932, 1941a; Gussow 1953). It is overlain by thin, shallow, marine, algal-bearing carbonates of the Gays River Formation (Boehner 1977; McCutcheon 1981) and deeper water, laterally equivalent, laminated carbonates of the Macumber Formation (Weeks 1948; McCutcheon 1981). The carbonate facies are followed by sulphates (gypsum and anhydrite) of the Upperton Formation (McCutcheon 1981).

In the Sackville and Cumberland subbasins, the sulphates are succeeded by rock salt and associated evaporites of the Pugwash Mine Formation. The name 'Pugwash Mine Formation' is introduced herein for New Brunswick in recognition of a correlated unit of rock salt in the Cumberland Subbasin of Nova Scotia, where Carter (1990) first used the name. Pugwash salt is overlain by the Lime-kiln Brook Formation, which records a series of transgressive tongues of marine carbonates and sulphates alternating with regressive tongues of terrestrial fine- to coarse-grained redbeds. As with the Pugwash Mine Formation, the name 'Lime-kiln Brook Formation' is introduced herein for the New Brunswick strata in recognition of its correlation with the type section at Lime-kiln Brook near Napan, Nova Scotia (Ryan and Boehner 1994).

Palynomorph and shelly fauna indicate that the Windsor Group of southeastern New Brunswick is early to middle Visean.

Mabou Group

The name 'Mabou Group' (Belt 1964, 1965) is adopted herein for New Brunswick to replace the name 'Hopewell Group' of Norman (1941a). In the Sackville and Cumberland subbasins, the Mabou Group conformably succeeds the Lime-kiln Brook Formation of the Windsor Group. Along the northwestern margins of those subbasins, the Mabou Group comprises proximal alluvial polymictic conglomerates and sandstones of the Hopewell Cape Formation (name introduced herein). The upper part of the Hopewell Cape Formation in the Dorchester area of the Sackville Subbasin is represented by a distinctive unit of fine-grained redbeds bearing abundant calcrete, lesser silcrete, and minor jasper. Those beds are herein named the 'Dorchester Cape Member' of the Hopewell Cape Formation. To the southeast and away from the margins of the Sackville and Cumberland subbasins, the coarse Hopewell Cape beds are replaced by a laterally equivalent sequence of redbeds that define a coarsening-upward megasequence. Ascending from the base, the megasequence comprises red mudrocks and minor sandstones of the Maringouin Formation (Norman 1941a), red and grey mudstones and sandstones of the Shepody Formation (Norman 1941a; Gussow 1953), and red friable conglomerates and grits of the Enragé Formation (Norman 1941a; Gussow 1953). The Hopewell Cape Formation and laterally adjacent Maringouin, Shepody, and Enragé formations define a classic proximal-to-distal alluvial fan complex.

On the southeastern shoulder of the Caledonia Uplift, on the Westmorland Uplift, on the Hastings Uplift, and in the eastern part of the Moncton Subbasin, the Mabou Group is restricted to a very condensed unit of mainly coarse redbeds assigned to the Hopewell Cape Formation (Fig. 9). On the uplifts and in the eastern Moncton Subbasin (in contrast with the Sackville and Cumberland subbasins), the Hopewell Cape Formation rests unconformably on 1) eroded rocks of the Windsor Group that are older than the Pugwash Mine Formation, 2) rocks of the Horton and Sussex groups, and/or 3) locally crystalline basement.

The Mabou Group ranges in age from middle Visean to early Namurian (Fig. 9, 15). An early Namurian date for the condensed section of Hopewell Cape Formation in the eastern Moncton Subbasin constrains the age of the unconformity at the base of the formation in that area. The boundary between the Mabou and Cumberland groups is a pronounced stratigraphic break that coincides with a major climatic change at the Mississippian–Pennsylvanian boundary (Utting et al. 2005). Palynological data for the Mabou and Cumberland groups demonstrate that the intervening disconformity–unconformity represents a time interval from early Namurian (Namurian A) to late Namurian (probably late Namurian C). The Namurian unconformity in the Maritimes Basin coincides with the Mississippian–Pennsylvanian intercontinental unconformity (Sloss 1963).

Cumberland Group

The Cumberland Group in New Brunswick is restricted to grey or red, typically texturally and mineralogically mature, fluvial, sandstone-dominated sequences that overlie the Enragé or Hopewell Cape formations and underlie the Salisbury or Minto formations. The revised Cumberland Group in southeastern New Brunswick comprises two formations: the Boss Point Formation and the overlying and, in part, time-equivalent Grande Anse Formation.

The Boss Point Formation is divided herein for the first time into four lithologically distinct and stratigraphically constrained members. The basal Chignecto Bay Member is confined to the Cumberland Subbasin and the southern flank of the Caledonia Uplift. It is characterized by distinctive dusky maroon or wine-coloured, ripple-laminated siltstones to fine-grained sandstones. Along the southern flank of the Caledonia Uplift, the Chignecto Bay Member is succeeded by the Breau Creek Member. The former member pinches out to the north. Therefore, in the Moncton and Sackville subbasins, the Breau Creek rests directly on the Mabou Group, thus defining the base of the Boss Point Formation in those areas. The Breau Creek Member is dominated by mature, well-rounded, quartz-pebble conglomerate and quartzose arenites, which are overlain by multistoried grey sandstones and pebbly sandstone with minor grey and rare red mudrocks of the Cole Point Member. In the Cumberland Subbasin, the Chignecto Bay Member is overlain by the Ward Point Member, which is dominated by fining-upward sequences of trough cross-bedded sandstone, fine-grained rippled sandstone, and grey mudrocks. Unique to the Ward Point Member are ostracod-bearing carbonaceous limestone, carbonaceous shale, and thin coal seams of lacustrine origin (Browne 1991).

Overlying the Ward Point Member on the Hastings Uplift is the Grande Anse Formation (Norman 1941a). It consists of pinkish grey and reddish brown, quartz-rich arenite and conglomerate. Fine-grained facies include reddish brown and minor bluish grey siltstone, mudstone, and very fine-grained to fine-grained sandstone. Repetitive fining-upward cycles comprising roughly subequal amounts of coarse- and fine-grained facies characterize the type section at Grande Anse.

Palynological data indicate that the Boss Point Formation is late Namurian C (late Yeadonian) to early Westphalian A (early Langsettian). Spore assemblages in the Cole Point Member are most similar to assemblages in the Grande Anse Formation and other Langsettian post-Boss Point formations of the Cumberland Group in the Joggins section (Utting et al. 2005). This suggests that the upper contact of the Boss Point Formation in the Moncton and Sackville subbasins is diachronous and, in part, temporally equivalent to post-Boss Point Cumberland strata in the Cumberland Subbasin.

Pictou Group

In southeastern New Brunswick, the Cumberland Group is succeeded by the Pictou Group, which there comprises the Salisbury, Richibucto, and Tormentine formations (Gussow 1953). On the New Brunswick Platform (Fig. 6), quartzose sandstones, mudrocks, and thin coal seams of the Minto Formation hold a stratigraphic position comparable with the Salisbury Formation of the Moncton and Sackville subbasins. The Pictou Group as defined herein is synonymous with the Morien Group on Cape Breton Island.

The Salisbury Formation is composed predominantly of red siltstone, sandstone, and mudstone along with a geographically restricted, newly recognized lower unit of mainly grey sandstone, the Colpitts Settlement Member. The conformably overlying Richibucto Formation is characterized by channel sequences of grey and lesser reddish brown, trough cross-bedded, micaceous, arkosic, and lithic sandstone; and mudstone-clast conglomerate. The channel sequences are separated by intervals of dominantly reddish brown, ripple-laminated to massive sandstone, siltstone, mudstone, and rare limestone.

In southeasternmost New Brunswick, the Richibucto Formation is overlain by the Tormentine Formation, a unit that resembles the Richibucto Formation except for having nearly exclusively red sandstones. The age of palynological samples from the Salisbury and Richibucto formations ranges from late Westphalian B (late Duckmantian) to Stephanian (Gzhelian). The Tormentine Formation is undated.

In the Sackville Subbasin and eastern Moncton Subbasin, the Pictou Group (Salisbury Formation) disconformably overlies the Cumberland Group. On the New Brunswick Platform, the disconformity at the base of the Pictou Group (Minto Formation) is evidenced by the late Westphalian B (late Duckmantian) to early Westphalian C (early Bolsovian) Minto Formation, which oversteps all older Carboniferous units and locally lies on exhumed early Paleozoic basement.

DISCUSSION

The advancements in lithostratigraphy described in this report have in good measure come from a concerted effort over a period of more than 25 years to collect samples for palynological analysis. During this process an emphasis has been made, first, to refine the age and age range of formations and with this data to determine the temporal relationship between and among formations in a group; and, second, to ascertain the location and value of time omitted at significant hiatuses (boundaries).

With respect to the first point, palynology has supported the lithostratigraphic field work, particularly in the highly structured Indian Mountain Deformed Zone and the southeastern Moncton Subbasin adjacent to the Caledonian Uplift. For instance, in the Horton Group, palynological assemblages have assisted in demonstrating the partial temporal equivalency of the McQuade Brook and Albert formations, and the Albert and Steeves Mills formations. In the Sussex Group, spore data helped to show the lateral relationship of the Round Hill Formation with the Gautreau and Weldon formations, and the association of the proximal Stilesville and Briggs Cross formations with their distal relatives, the Gautreau and Weldon formations.

Concerning the second point, three examples can be offered of significant advances made regarding boundary definitions: 1) the discovery of a middle Tournaisian disconformity–unconformity between the Horton and Sussex groups, 2) the demonstration of a large Namurian time gap between the Mabou and Cumberland groups, regardless of the fact that those groups are virtually in parallel disposition in the Sackville and Cumberland subbasins, and 3) the evidence of a middle Westphalian B (Duckmantian) disconformity between the Cumberland and Pictou groups in southeastern New Brunswick where no angular discordance of bedding or loss of section is obvious.

The authors' decision to augment lithostratigraphy with sequence stratigraphy in defining group boundaries in New Brunswick will no doubt be questioned. Using sequence stratigraphy in this context can present advantages and disadvantages. For example, Ryan et al. (1991) noted that their criteria for assigning formations to either the Cumberland or Pictou groups were not encumbered by age connotations and were based primarily on unifying lithological characteristics. However, a purely lithostratigraphic approach to group definition, although demanded by the Stratigraphic Code, is unrealistic when applied to continental fluvial successions. This was obvious to gas and oil industry geologists such as Gussow (1953, p. 1753), who remarked that some of his fivefold divisions of Pennsylvanian strata were "based chiefly on lithology, which brings their validity in some doubt."

As sequence stratigraphy has shown, unconformity-bounded units explain geological history more successfully than does lithostratigraphy alone (e.g., Gutteridge 2008; Rasanan et al. 2009). Regardless of stratigraphical and palynological evidence that demonstrates regional disconformities–unconformities at the group boundaries, a more important question is whether the successions bounded by unconformable surfaces comprise 'naturally related' groups of rocks. It is concluded herein that they do. Although the present authors acknowledge it is locally difficult to distinguish group boundaries on a purely lithological basis, the practice is still more tolerable than correlating lithologically similar but unrelated rock units.

One of the most significant findings of the stratigraphic work reported herein is the observation that, almost without exception, the terrestrial formations of the Horton, Sussex, Windsor, and Mabou groups show remarkable variations in thickness over short distances. For example, it is not uncommon for units greater than 1 km thick to pinch out to a zero edge over a distance of less than 30 km, or to have a tenfold decrease in thickness over a lateral distance of 5 km. The abrupt thickness variations of formations reflect the dimensions of the subbasins (depocentres) in which they were deposited and the proximity of crystalline source areas. The result is that coarse-grained, proximal conglomerate- and sandstone-dominated units typically have a wedge-shaped geometry with the thicker part of the wedge lying adjacent to provenance areas. Conversely, fine-grained, mudstone-dominated formations are lenticular with the thickest part of the lens in the axial or central part of depocentres.

A corollary of the foregoing observation is that the thickness of the groups themselves is typically far more regionally consistent than that of their constituent formations. This is exemplified by the Mabou Group in the Sackville Subbasin. There, the proximal Hopewell Cape Formation is about 800 m thick adjacent to its bounding escarpment, the Harvey–Hopewell Fault, whereas its equivalent distal formations — the Maringouin, Shepody, and Enragé — have a similar but aggregate thickness of approximately 800 m in the axial part of the subbasin.

In contrast with the redbed formations of the Horton, Sussex, Windsor, and Mabou groups, the formations of the Cumberland and Pictou groups show much greater regional consistency in thickness. Compare, for example, the tabular shape of the Boss Point or Salisbury formations (Fig. 13) with the wedge shape of the Steeves Mills or Weldon formations (Fig. 14). The tabular shape of the Cumberland and Pictou units is a consequence of the regional base level established at the Mississippian–Pennsylvanian unconformity, the resultant broader dimensions of the Late Carboniferous basin, and the concomitant influx of more distal sources of detritus (Gibling et al. 1992).

The enhancements in knowledge concerning thickness variations and formational chronology within the Horton, Sussex, Windsor, and Mabou groups have been coupled with more comprehensive information on the composition and clast content of conglomerates and sandstones. This information has helped to demonstrate that depocentres typically had more than one principal source area. The Westmorland Uplift, for instance, was widely considered to be a largely passive basement block during Horton time. However, the Steeves Mills Formation was clearly sourced from the Westmorland Uplift, as was the Memramcook Formation in its type area (Foley 1989; St. Peter 1992). The partial temporal equivalent of the Steeves Mills Formation, the Albert Formation, yields proof that the Moncton Subbasin during Horton time was bipolar, receiving input from both the Caledonia (Pickerill and Carter 1980; Pickerill et al. 1985; St. Peter 1992) and Westmorland basement blocks. Three source areas have been identified for sediment in the Sussex Group: the Caledonia Uplift for the Round Hill Formation and associated distal equivalents, the Westmorland Uplift for the Stilesville and Briggs Cross formations and their distal equivalents (St. Peter 2006a), and the New Brunswick Platform for the Ridge Brook Formation (St. Peter 2006a).

After completing his scientific editing of the current report, Dr. Peter Giles posed two questions concerning the stratigraphy of the late Windsor successions in the Sackville and

Cumberland subbasins in New Brunswick. First, why choose nomenclature from the Cumberland Subbasin of Nova Scotia for an unnamed unit of rock salt and an unnamed overlying unit of intertonguing marine carbonates, evaporites, and terrestrial clastics in the Sackville and Cumberland subbasins in New Brunswick? Second, is there a hiatus between Cycle 1 and Cycle 2 of the Windsor successions in the Sackville and Cumberland subbasins?

The question of nomenclature is addressed first. It should be recalled that, when this study began, the units of thick rock salt and overlying marine and terrestrial strata in the Sackville and Cumberland subbasins in New Brunswick were not formally named. Consequently, the available choices were either to create two new names (one for the rock salt unit and one for the overlying beds) or to apply existing names from an adjacent basin and thus imply regional correlation. Consultation with other geologists familiar with Maritimes Basin stratigraphy indicated the latter approach as the better choice. Therefore, the present authors used the established nomenclature of the late Windsor Group of Ryan and Boehner (1994) in the spatially closest depocentre, the Cumberland Subbasin in Nova Scotia, for the rock salt unit (Pugwash Mine Formation) and the overlying marine and terrestrial unit (Lime-kiln Brook Formation) in the Sackville and Cumberland subbasins in New Brunswick.

Another available choice would have been to use the established nomenclature of the western Moncton Subbasin, such as the Cassidy Lake Formation and overlying Clover Hill Formation (Anderle et al. 1979; McCutcheon 1981; Roulston and Waugh 1981; Waugh and Urquhart 1985). However, the western Moncton Subbasin correlation was considered second-best because the relatively clean rock salt in the Sackville Subbasin is lithologically more similar to the rock salt of the Pugwash Mine Formation in Nova Scotia than to the potash-bearing chlorides (sylvinite) of the Cassidy Lake Formation. Another point in favour of using established nomenclature from the Cumberland Subbasin was that the Lime-kiln Brook Formation in Nova Scotia was considered a Cycle 2 Windsor unit (Ryan and Boehner 1994, their Fig. 2-5). Thus, it was biostratigraphically comparable with macrofaunal-bearing carbonates in New Brunswick, which had been recently confirmed as Cycle 2 beds (Moore 1996). The Clover Hill Formation in the western Moncton Subbasin, on the other hand, was conformable with the underlying Cassidy Lake salt, interpreted as a Cycle 1 or Subzone A (Bell 1929) unit (McCutcheon 1981, his Table 4-1).

For these reasons, the present authors selected the late Windsor nomenclature from Nova Scotia's Cumberland Subbasin to name the uppermost Windsor units of the Sackville and Cumberland subbasins in New Brunswick. Yet several unresolved issues of correlation remain. Borehole logs of cuttings and cores from the Sackville Subbasin indicate that the thick rock salt-bearing unit (Pugwash Mine Formation) lies concordantly and gradationally above the basal sulphate unit (Upperton Formation) and accordingly is interpreted as a Cycle 1 chloride unit. However, correlation of the rock salt in the Sackville Subbasin with the Pugwash Mine Formation of Nova Scotia is somewhat tentative. For example, the nature of the basal contact of the Pugwash Mine Formation in Nova Scotia is unknown, as it is neither exposed nor drilled. Nonetheless, no other thick, clean rock salt is known to exist in the Cumberland Subbasin that provides a more certain correlation for the salt in the Sackville Subbasin.

Correlation of the section of Windsor strata above the rock salt of the Pugwash Mine Formation in the Sackville Subbasin is also problematical. None of the sections in Wells 325, 330, 711, and 716 contain limestone tongues, and therefore they are dissimilar to characteristic Cycle 2 Windsor units in Nova Scotia (Giles 1981). The Sackville well sections provide equivocal evidence of the type of contact between the Pugwash Mine salt and the overlying nominal beds of the Lime-kiln Brook Formation. The boundary may be concordant in the central part of the subbasin and almost certainly is marked by erosion near the basin margin. No microfloral or microfaunal data are available from grey mudstones in the well sections to identify the post-Pugwash Mine beds as Cycle 1 or Cycle 2. Lithotypes in the sections above the salt in the Sackville Subbasin are more closely comparable with rocks of the Clover Hill Formation (Cycle 1) of the western Moncton Subbasin than with the carbonate-bearing Lime-kiln Brook Formation of the Cumberland Subbasin of Nova Scotia. On the other hand, it is difficult to rationalize how Cycle 2 fossiliferous, carbonate-bearing Lime-kiln Brook strata on the margin of the Sackville Subbasin at Lower Cape and Upper Dorchester could be absent in the deeper part of the basin where the well sections are located. For now, the rocks above the salt are correlated with the Lime-kiln Brook Formation that is exhumed on the subbasin margin.

And now to address Dr. Giles's question concerning a hiatus between Cycle 1 and Cycle 2 successions of the Windsor Group in the Sackville and Cumberland subbasins. In several successions (depocentres) in Nova Scotia, a hiatus (that is, a surface of exposure and/or erosion) has been documented or interpreted at the top of Cycle 1 of the Windsor Group (Giles 1981; von Bitter et al. 2007). Is there a comparable stratigraphic break in the Windsor succession of the Sackville and Cumberland subbasins in New Brunswick? As with the nomenclature question, the currently available data make it impossible to answer the hiatus question unequivocally. In the Sackville and Cumberland subbasins, the successions are interpreted to show that those depocentres continued to subside during the retreat of the Windsor Sea. Consequently, sedimentation there was apparently continuous across the boundary of the Windsor and Mabou groups, and no evidence exists of a post-Cycle 2 disconformity in those subbasins. However, the eastern part of the contiguous Moncton Subbasin tells a different story. There, the absence of Pugwash Mine and Lime-kiln Brook formations (Windsor Group) and a very condensed Hopewell Cape Formation (Mabou Group) indicate that the area, in late Visean time, underwent a period of uplift and erosion. Did that uplift also affect the continuity of Cycle 1–Cycle 2 sedimentation in the Sackville and Cumberland subbasins? We don't know.

In early Pennsylvanian time, a paleogeographic high, the Hasting Uplift (Fig. 6), existed in the area now underlain by the Grande Anse Formation (Browne 1991, his Fig. 8.3). The uplift was bounded on the south by the Shepody–Beckwith Fault and divided the western Cumberland Subbasin into two domains (Fig. 6, 84), shedding detritus northward north of the Shepody–Beckwith Fault and southward south of the fault. Notwithstanding the evidence of a conformable contact between the lowermost Grande Anse beds and the Boss Point Formation in the Hard Ledges Syncline (Fig. 72), potentially contrary evidence suggests localized erosion of Boss Point strata, concomitant with continued subsidence in the Cumberland Subbasin. For example, conglomerates in the Grande Anse Formation north of the Shepody–Beckwith Fault contains clasts of grey quartzose sandstone. The clasts apparently are not intraformational. Instead, they were lithified at the time of incorporation and are lithologically similar to beds in the Boss Point Formation. If the clasts were sourced from the Boss Point Formation, the implication is that the Boss Point strata underwent a period of uplift and erosion, possibly reflecting the rise of the Hastings basement block. Note that the Grande Anse Formation is geographically restricted to the area overlying the Hastings Uplift, suggesting that the uplift played a role in the deposition and/or preservation of the unit.

When Gulf et al. drilled into the Hastings Uplift just east of Amherst (Fig. 6) in Nova Scotia (Howie 1986), the well (Hastings No. 1) encountered basement at a depth of about 2.8 km. Late Cumberland strata in the well are underlain by a thick section of Boss Point Formation, indicating that the Boss Point in that area most likely was *not* the source of grey sandstone clasts in the Grande Anse Formation. However, on the western end of the Hastings Uplift beneath the waters of Shepody Bay and near Cape Station, basement rocks of the uplift are potentially exhumed. Therefore, it is possible that the Boss Point in that district was partly or even completely eroded and so represents a plausible source of clasts in the overlying Grande Anse Formation.

CHAPTER 3

STRUCTURAL GEOLOGY

INTRODUCTION

The first chapter of this report (under ***Regional Geology***) gives references to several papers that provide overviews of the origin and amalgamation history of the terranes forming the foundation beneath the Maritimes Basin. Deformation affecting those basement terranes, and in particular the strain associated with terrane-bounding faults and intraterrane faults in New Brunswick and Nova Scotia, have been variously described by Eisbacher (1969), Brown and Helmstaedt (1970), Rast and Stringer (1974), Ruitenberg et al. (1977, 1979), Keppie (1982), Rast and Dickson (1982), Leger (1986), McLeod (1986), Mawer and White (1987), Nance (1987), Barr and White (1991, 1996), van Staal and Fyffe (1995a, 1995b), van Staal et al. (1996, 1998), Hibbard et al. (2006), and van Staal (2007).

Subsequent post-Devonian reactivation of many of the terrane-bounding 'old faults' was mentioned or implied by most of the above authors. More specifically, the major faults associated with the inception of subbasins and subsequent deformation of rocks in the Maritimes Basin of New Brunswick was detailed by Gussow (1953), Webb (1963, 1969), Belt (1968), Rast and Grant (1973), Keppie (1982), Ruitenberg and McCutcheon (1982), Leger and Williams (1986), Nance (1986), Nance and Warner (1986), Yeo and Ruixing (sic) (1986), St. Peter (1992, 1993, 2006a), Nickerson (1994), Wilson (2002, 2005), Park and St. Peter (2005, 2009), Wilson et al. (2006), and Park et al. (2007).

The regional deformation affecting Late Devonian–Permian rocks in the Maritimes has been ascribed to the Maritime Disturbance (Poole 1967), Variscan Orogeny (European terminology), or Alleghenian Orogeny (USA Appalachian terminology). The oblique transpressional collision of the Gondwanan and Laurentian continents has been invoked to explain the diachronous nature of orogenesis in the Maritime provinces of Canada (Late Devonian to Early Carboniferous (Variscan)) compared with that in the southern Appalachian area of the United States (Late Carboniferous to Permian (Alleghenian); Hatcher 2002). In the Maritimes region, the Meguma terrane (Fig. 5), interpreted as a fragment rifted off Gondwana (Schenk 1971), is generally postulated to have drifted across the Rheic Ocean and, with the closure of that seaway, to have accreted to Avalonia in the late Paleozoic. However, Murphy et al. (1999) contend that the Meguma had accreted to Avalonia before the late Paleozoic.

In southern New Brunswick, the major early Paleozoic northeast-trending, terrane-bounding faults and associated lesser intraterrane faults have been ascribed to the docking of Avalonia with Ganderia (Fyffe and Fricker 1987; Barr and White 1996; Schreckengost and Nance 1996; Whalen et al. 1996; Johnson 2001; Barr et al. 2003; Hibbard et al. 2006; van Staal 2007). The faults were reactivated as a result of the collision of Meguma with Avalonia in the late Paleozoic. The major zones of ductile strain in the basement terranes are reflected as focused zones of intense brittle deformation in the overlying cover rocks of the Maritimes Basin (Leger and Williams 1986).

The principal zones of brittle deformation affecting the Maritimes Basin in the report area are 1) the northwestern margin of the Cocagne Subbasin, 2) the Indian Mountain Deformed Zone that defines the boundary of the Westmorland Uplift and Cocagne Subbasin (Fig. 6, 10), 3), the southeastern margin of the Moncton Subbasin, 4) the northwestern margins of the Cumberland and Sackville subbasins, and 5) the margins of the Cumberland and Sackville subbasins against the Hastings Uplift (Fig. 84; Table 9). In other words, most of the strain caused by the multiple reactivations during and subsequent to formation of the Maritimes Basin is focused in zones along the contacts between 'harder' crystalline basement blocks and 'softer' thick sequences of sediment in the subbasins.

Deformation in those principal zones is typically characterized by the presence of two or three northeast-trending master faults combined with several linking secondary faults. Strain is also accommodated along less significant north- to northwest-trending cross faults. Shortening of the sections is shown by steep, vertical, or even locally overturned bedding. Folds appear in less competent rocks such as thick shales, mudstones, and evaporites but in the report area played a far lesser kinematic role than faults (see Webb 1963, 1969). The faults ultimately controlled the several inversions of fill in the subbasins, as amply demonstrated by unconformities between the groups. Those inversions and the subsequent exhumation of beds are the main factors contributing to the present map pattern as portrayed in Plates 1 to 6.

These general statements are well supported by the available evidence. They demonstrate that several major northeast-trending, long-lived faults had a profound influence on subbasin inception(s), sedimentation history, and the subsequent phases of uplift and inversion. Less certain is our understanding about the timing, sense, and magnitudes of displacement of those faults during each reactivation phase (Gussow 1953; Belt 1965; Webb 1963, 1969; Bradley 1982; St. Peter 1992, 1993; Nickerson 1994; Park and St. Peter 2005, 2009; Wilson and White 2006; Park et al. 2007).

Bradley (1982) advanced a conceptual model of the Maritimes Basin as a two-part structure comprising a Late Devonian–Early Carboniferous strike-slip-dominated, pull-apart basin followed by a more widespread Middle–Late Carboniferous thermal-subsidence sag basin. It is true there was an early phase in which the individual subbasins were formed and filled with mainly locally derived deposits (Horton, Sussex, Windsor, and Mabou groups), and a later phase when a mainly regionally derived and widely distributed cover sequence (Cumberland and Pictou groups) was deposited. The basal unit of the Cumberland Group (Boss Point Formation) is the first regionally distributed, compositionally mature (quartzose), and mainly distally derived deposit in the Maritimes Basin (Gibling et al. 1992). Its base defines the most significant unconformity in the Carboniferous stratigraphic succession (Fig. 9) and thus marks a major change in basin morphology and dynamics. Bradley (1982) restricted the early extensional–transtensional phase to the Early Carboniferous (Tournaisian and Visean). However, subbasins with locally derived detritus were subsiding and being filled as late as the Westphalian. Such sediment is well exemplified by the Cumberland Group (Ryan et al. 1991; Ryan and Boehner 1994) and the Stellarton Group (Yeo and Ruixiang 1987).

Was the tectonic–kinematic regime responsible for basin formation dominantly strike slip or dip slip? Little doubt exists that strike-slip displacements occurred on many regional and subbasin-bounding faults during the Carboniferous (Webb 1963, 1969; Eisbacher 1969; Hyde

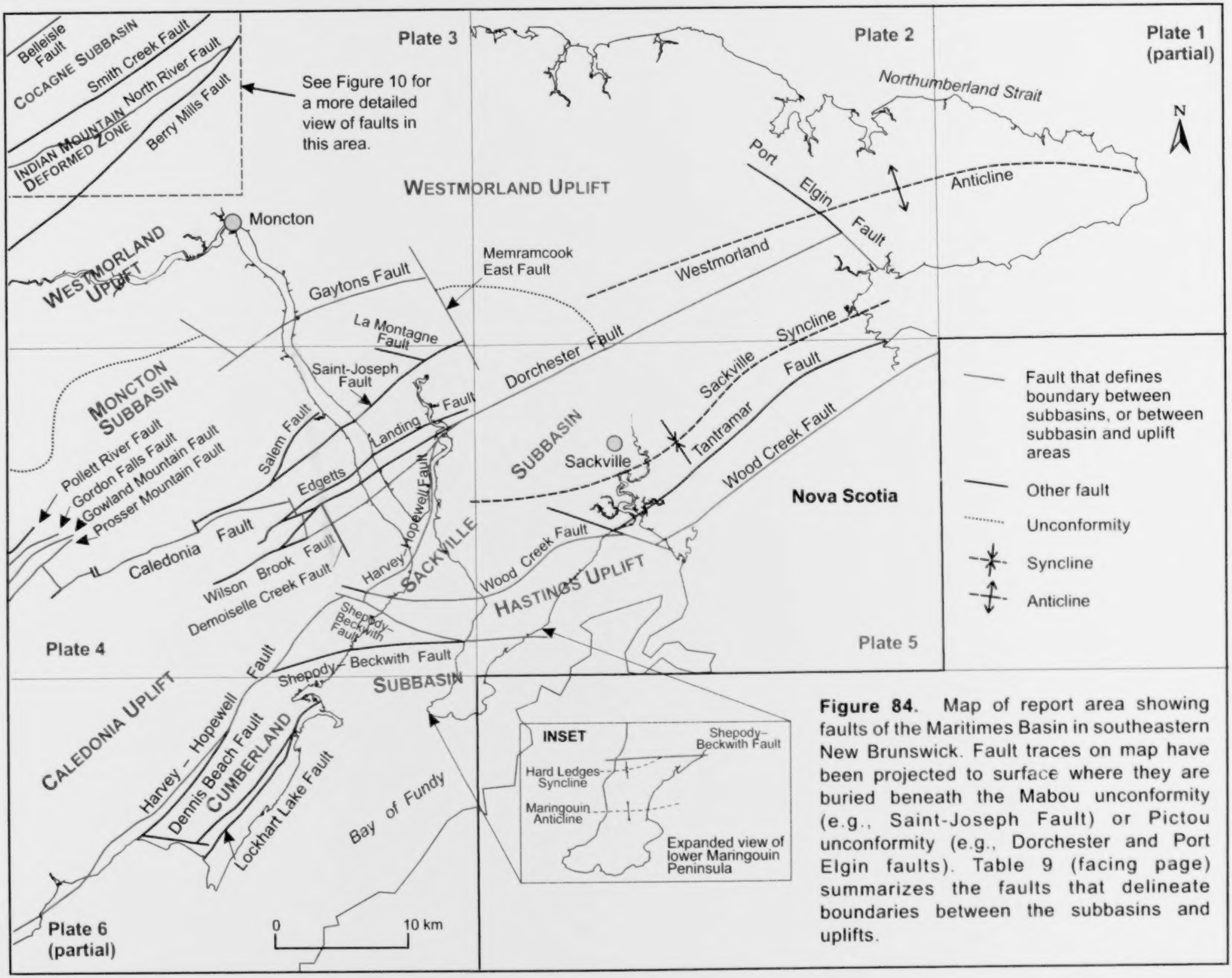


Plate 3
Plate 2
Plate 1 (partial)
Plate 4
Plate 5
Plate 6 (partial)
Belleisle Fault
COCAGNE SUBBASIN
Smith Creek Fault
North River Fault
INDIAN MOUNTAIN DEFORMED ZONE
Berry Mills Fault
See Figure 10 for a more detailed view of faults in this area.
Northumberland Strait
N
Port Elgin Fault
Anticline
WESTMORLAND UPLIFT
Moncton
WESTMORLAND UPLIFT
Memramcook East Fault
Gaytons Fault
Westmorland
La Montagne Fault
Dorchester Fault
Syncline
Sackville
Fault
Saint-Joseph Fault
Landing Fault
Tantramar
Wood Creek Fault
MONCTON SUBBASIN
Pollett River Fault
Gordon Falls Fault
Gowland Mountain Fault
Prosser Mountain Fault
Salem Fault
Edgetts
SUBBASIN
Sackville
Nova Scotia
Caledonia Fault
Wilson Brook Fault
Demoiselle Creek Fault
Harvey–Hopewell Fault
SACKVILLE
Wood Creek Fault
HASTINGS UPLIFT
Shepody–Beckwith Fault
Shepody–Beckwith Fault
SUBBASIN
Fault that defines boundary between subbasins, or between subbasin and uplift areas
Other fault
Unconformity
Syncline
Anticline
CALEDONIA UPLIFT
Harvey – Hopewell Fault
Dennis Beach Fault
CUMBERLAND
Lockhart Lake Fault
Bay of Fundy
0
10 km
INSET
Shepody–Beckwith Fault
Hard Ledges Syncline
Maringouin Anticline
Expanded view of lower Maringouin Peninsula

Figure 84. Map of report area showing faults of the Maritimes Basin in southeastern New Brunswick. Fault traces on map have been projected to surface where they are buried beneath the Mabou unconformity (e.g., Saint-Joseph Fault) or Pictou unconformity (e.g., Dorchester and Port Elgin faults). Table 9 (facing page) summarizes the faults that delineate boundaries between the subbasins and uplifts.

Table 9. Faults that define boundaries between subbasins, or between subbasin and uplift areas.

Fault	Boundary-Defining Role(s)
Belleisle Fault	Defines northwestern boundary of Cocagne Subbasin with New Brunswick Platform
Smith Creek Fault	Defines northwestern boundary of Indian Mountain Deformed Zone within Cocagne Subbasin
North River Fault	Defines southeastern boundary of Cocagne Subbasin with Westmorland Uplift
Berry Mills Fault	Defines southeastern boundary of Indian Mountain Deformed Zone within Westmorland Uplift
Gaytons Fault	Defines part of northwestern boundary of Moncton Subbasin with Westmorland Uplift
Gordon Falls Fault	Locally defines boundary of Moncton Subbasin with Caledonia Uplift just southwest of report area
Gowland Mountain Fault	Locally defines boundary between Moncton Subbasin and Caledonia Uplift
Prosser Mountain Fault	Locally defines boundary between Moncton Subbasin and Caledonia Uplift
NW-trending fault at Prosser Brook	Locally defines boundary between Moncton Subbasin and Caledonia Uplift
Caledonia Fault	Defines southeastern boundary of Moncton Subbasin with Caledonia Uplift from Prosser Brook northeastward to Frederick Brook (note: Saint-Joseph Fault is a major splay of the Caledonia Fault within the Moncton Subbasin)
NW-trending fault west of Frederick Brook	Locally defines boundary between Moncton Subbasin and Caledonia Uplift
Wilson Brook Fault	Defines southeastern boundary of Moncton Subbasin from ~3 km southwest of Albert Mines northeastward to Upper Dorchester
Dorchester Fault	Defines southeastern boundary of Moncton Subbasin from Upper Dorchester eastward for 15 km; defines northwestern boundary of Sackville Subbasin from Upper Dorchester northeastward to Port Elgin Fault
Memramcook East Fault	Locally defines eastern boundary of the Moncton Subbasin with the Westmorland Uplift
Harvey–Hopewell Fault	Defines northwestern boundary of Cumberland Subbasin with Caledonia Uplift from Point Wolfe to Hamilton Creek; defines western boundary of Sackville Subbasin from Cape Station to Upper Dorchester
Shepody–Beckwith Fault (northern splay)	Defines northern boundary of Cumberland Subbasin with Hastings Uplift
Port Elgin Fault	Defines northeastern boundary of Sackville Subbasin with Westmorland Uplift from Dorchester Fault southward
Wood Creek Fault	Defines southern boundary of Sackville Subbasin with Hastings Uplift

1979; Leger and Williams 1986; Mawer and White 1987; Yeo and Ruixiang 1987). However, more recent evidence indicates that the dominant sense of movement on many faults along subbasin margins was in fact dip slip or oblique slip. This is evidenced by 1) the graben and half-graben shapes of many subbasins (Knight 1983; Hamblin 1989, 1992; Nickerson 1994; Lynch and Giles 1996), 2) the steeply pitching slickensides on many faults (Knight 1983; herein, this chapter), and most importantly 3) the fact that, in nearly every subbasin–margin alluvial fan complex, the detritus is demonstrably derived from closely adjacent basement uplifts (Belt 1968; Hyde 1979; Knight 1983; Hamblin 1989; St. Peter 1993; Ryan and Boehner

1994; herein, Chapter 2). This third point demonstrates that limited lateral offset took place along most subbasin–margin faults and strongly suggests that extension or transtension — not strike-slip movement — was the primary tectonic environment under which the early subbasins of the Maritimes Basin developed.

To resolve the conflicting interpretations regarding the kinematic history of the major fault zones in the report area, recent structural work has focused on the Indian Mountain Deformed Zone and the southeastern margin of the Moncton Subbasin. Part of this chapter summarizes investigative results from Wilson (2002), Park and St. Peter (2005, 2009), and Park et al. (2007). The chapter is divided into five parts that examine the five main structural zones: the northwestern margin of the Cocagne Subbasin, the Indian Mountain Deformed Zone, the eastern Moncton Subbasin, the Cumberland Subbasin, and the Sackville Subbasin. The chapter is subtitled mainly according to the key faults within each of the structural zones but also discusses some intrabasinal synclines and anticlines. Table 9 summarizes what are currently interpreted as the boundary-defining faults in the report area, those being faults that define boundaries between subbasins or between subbasins and uplift areas (Fig. 84).

NORTHWESTERN MARGIN OF COCAGNE BASIN STRUCTURE

Belleisle Fault

The Belleisle Fault is a major fault that defines the boundary between the New Brunswick Platform on the northwest and the Cocagne Subbasin on the southeast (Fig. 6, 84). The New Brunswick Platform is an uplifted area of early Paleozoic basement and in the report area is overlain by only a few hundred metres of strata of the Pictou Group.

The Belleisle Fault was variously interpreted by early workers. Gussow (1953) considered that the nature of the 'Carboniferous' displacement on the fault was reverse or thrust and directed toward the southeast, and that the fault plane dipped to the northwest. He cited no evidence to support his interpretation. Garnett and Brown (1973) dismissed the possibility of major strike-slip movement on the fault, yet Webb (1963) and Ruitenberg et al. (1979) interpreted late (Variscan?) dextral strike-slip movement. Belt (1968) provided circumstantial evidence of the Carboniferous having undergone relative displacement on the Belleisle Fault. He noted that Horton strata were absent on the New Brunswick Platform (northwest) side of the break but were locally present in thicknesses of up to 3 km on the southeast side of the fault. This, suggested Belt, implied a significant Early Carboniferous down-to-the-southeast movement.

Data from Well 713, about 15 km southwest of Pacific Junction and 2.5 km south of the Belleisle Fault (see St. Peter 2006a, his Fig. 5), substantiate Belt's interpretation. ***(See Appendix 1 for details about this and all other numbered wells cited in Chapter 3.)*** In that well, more than 2 km of alluvial and fluvial strata of the Horton Group, apparently of the Memramcook Formation, was drilled without reaching basement. The presence of this thick, proximal, conglomerate-dominated sequence adjacent to the fault suggests it was a basin-bounding structure active during Horton time. Northeast of Well 713, broken reflectors appear on a Mini-Sosie shallow seismic reflection line shot along Highway 126 (Fig. 10; Plate 3; Steeves and Kingston 1981). The broken reflectors near the Belleisle Fault lie in the Pictou Group, indicating a minor Late Carboniferous or younger down-to-the-southeast displacement on the fault. The major displacement on the Belleisle Fault is assumed to be down-to-the-southeast and normal dip slip or oblique dip slip as a result of Late Devonian–Early Carboniferous extension and/or transtension. Significant late Paleozoic lateral translation along the fault remains unproven.

INDIAN MOUNTAIN DEFORMED ZONE STRUCTURE

The Indian Mountain Deformed Zone (IMDZ) is a northeast-trending, structurally complex panel of basement, Horton, and Sussex rocks exposed north of Moncton (Fig. 6, 10, 84, 85; St. Peter 2006a; Park and St. Peter 2009). It is bounded on the north by the Smith Creek Fault and on the south by the Berry Mills Fault. The major North River Fault divides the IMDZ internally into two parts (Fig. 10): a southeast-facing panel of Horton rocks on the north and a block of crystalline basement with a cover of local Horton inliers and a thick succession of Sussex rocks on the south (Fig. 10, 85). The panel of Horton strata on the north is approximately 3 km thick and represents an exhumed part of the Cocagne Subbasin (St. Peter 2006a; Park and St. Peter 2009). The south panel of crystalline rocks with associated Horton inliers (Memramcook Formation) and Sussex cover is an exhumed part of the Westmorland Uplift. Both the basement and inlier are unconformably capped by a thick sequence of Sussex strata of the Stilesville, Gautreau, and Briggs Cross formations.

Smith Creek Fault

The Smith Creek Fault (Gussow 1953) is the northwest-bounding fault of the IMDZ within the Cocagne Subbasin (Fig. 10, 84). Its surface trace is marked by an obvious northeast-trending topographic lineament between Catamount and O'Neil. In this area, it juxtaposes the McQuade Brook Formation on the southeast against the Ridge Brook and Minto formations on the northwest. The fault has a surface trace of about 75 km from McQuade Brook in the northeast to Smith Creek near Sussex in the southwest (Fig. 6).

The Smith Creek Fault is interpreted to dip steeply to the southeast, at least in the shallow subsurface. A steep dip is implied by the straight trace of the fault. The dip interpretation is also based on evidence from several seismic reflection profiles across the structure. The relative ages of formations on either side of the fault indicate it moved up on the southeast. The amount of displacement is less obvious. For example, results from the shallow seismic reflection line mentioned above suggest that the subhorizontally disposed Minto Formation lies unconformably on more steeply dipping beds of the Horton Group and possibly the Sussex Group at a time-depth of about 160 m. The Minto Formation is eroded on the southeast, hanging-wall side of the fault in this area. Such a relationship suggests at least 160 m of dip displacement in post-Pictou time.

The total post-Horton movement is less certain. Gussow (1953, his Fig. 9) interprets about 1.8 km of dip-slip offset in Sussex rocks at North River (20 km southwest of Pacific Junction), but the interpretation herein (Fig. 85) suggests his estimate is excessive. A dip-slip displacement of about 800 m to 1000 m on the basement and overlying Horton strata is more likely. Given this displacement, it is interpreted herein that most of the reverse throw on the Smith Creek Fault took place after Horton deposition but before Pictou deposition.

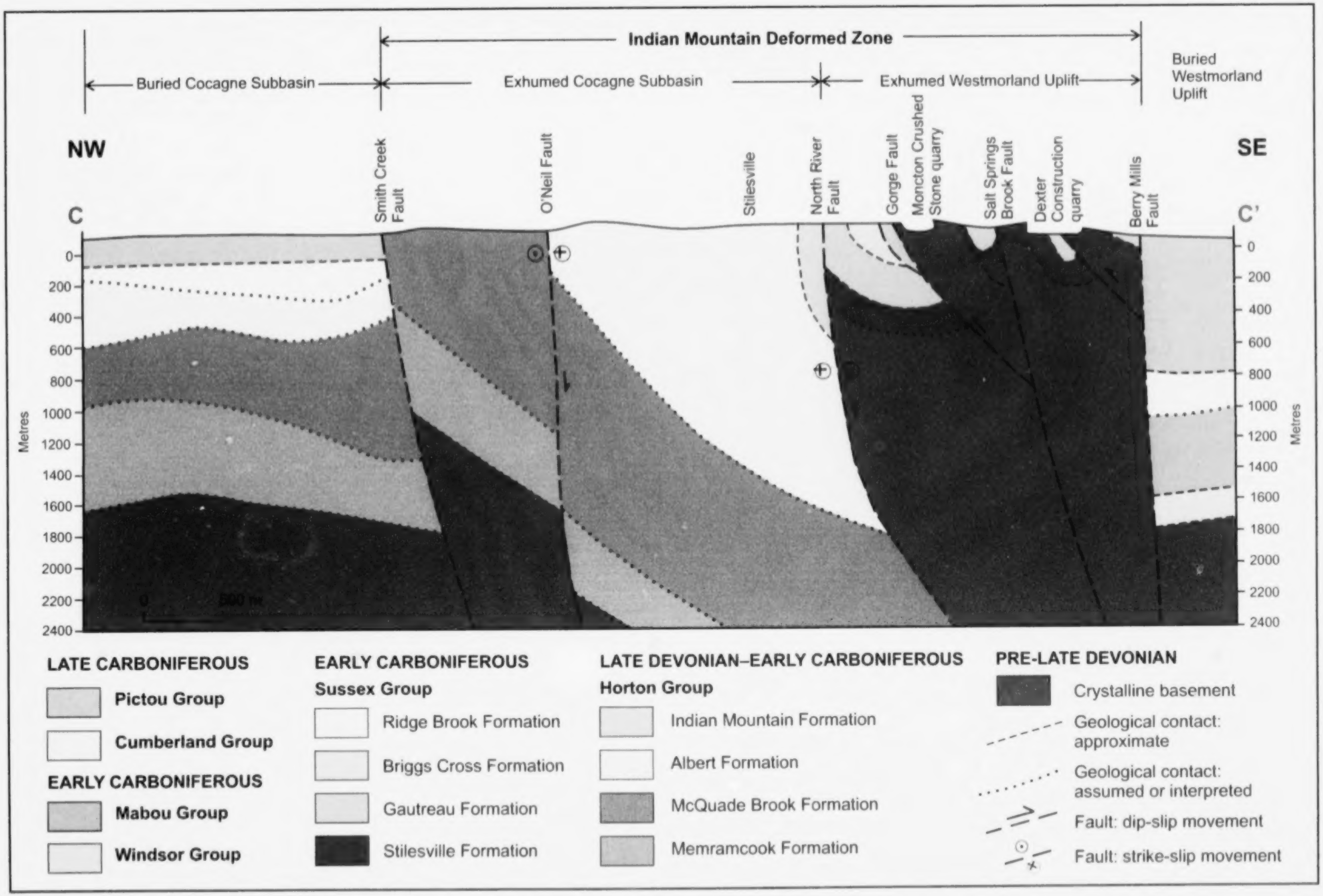

Indian Mountain Deformed Zone
Buried Cocagne Subbasin
Exhumed Cocagne Subbasin
Exhumed Westmorland Uplift
Buried Westmorland Uplift
NW
SE
C
C'
Smith Creek Fault
O'Neil Fault
Stilesville
North River Fault
Gorge Fault
Moncton Crushed Stone quarry
Salt Springs Brook Fault
Dexter Construction quarry
Berry Mills Fault
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Metres
0
500 m
LATE CARBONIFEROUS
Pictou Group
Cumberland Group
EARLY CARBONIFEROUS
Mabou Group
Windsor Group
EARLY CARBONIFEROUS
Sussex Group
Ridge Brook Formation
Briggs Cross Formation
Gautreau Formation
Stilesville Formation
LATE DEVONIAN–EARLY CARBONIFEROUS
Horton Group
Indian Mountain Formation
Albert Formation
McQuade Brook Formation
Memramcook Formation
PRE-LATE DEVONIAN
Crystalline basement
Geological contact: approximate
Geological contact: assumed or interpreted
Fault: dip-slip movement
Fault: strike-slip movement

Figure 85. Cross-section (C–C' on Plate 3) of the Indian Mountain Deformed Zone, which represents an exhumed part of the Westmorland Uplift juxtaposed against an exhumed part of the Cocagne Subbasin. Interpretation is based in part on structural data from St. Peter and Park (2006a, 2006b), Park and St. Peter (2009), and public seismic reflection profiles.

The Smith Creek Fault almost certainly underwent some dextral offset. Several dip reversals in beds of the McQuade Brook and Albert formations along McQuade Brook (Fig. 10) suggest the existence of folds with north-northeast-trending axes oriented en échelon to the trace of the Smith Creek Fault. If the folds and fault are related, offset along the fault could be interpreted as right-lateral movement (see Wilcox et al. 1973 for definition of the handedness of folds in wrench-fault systems). Note that fold closures were not actually observed in outcrops along McQuade Brook and that dip reversals could have resulted from tilted fault blocks.

O'Neil Fault

The O'Neil Fault lies about 1 km southeast of the Smith Creek Fault within the IMDZ (Fig. 10). The surface traces of the two faults are interpreted to unite north of Pacific Junction (Plate 3). As with the Smith Creek Fault, the O'Neil Fault trace is marked by a very prominent northeast-trending topographic lineament. The fault location is indicated by discordance of bedding attitudes in the McQuade Brook and Albert formations on either side of the surface trace. The fault juxtaposes the McQuade Brook Formation on the north against the Albert Formation on the south and accordingly is interpreted to have a normal, down-to-the-south component of movement (Fig. 85). The fault is poorly exposed in a drainage ditch that issues from the north side of the Victoria Road quarry (Fig. 10; Plate 3). There, the McQuade Brook Formation comprises subhorizontally dipping, reddish brown mudstone, which adjacent to the fault has a northeast-striking and subvertical-dipping fracture cleavage. The reddish brown mudstone beds are juxtaposed against dark grey kerogenous dolomitic siltstone, greyish black shale, and ferruginous sandstone of the Albert Formation.

The structure in the Albert Formation exposed on the Victoria Road quarry floor is detailed in Park and St. Peter (2009) and summarized as follows. Two phases of folding are evident in the Albert strata. The earlier phase (F_1) shows a consistent asymmetry, with axes plunging to the southwest. An axial planar cleavage (S_1) is present, especially in the dolomitic layers, where the cleavage–bedding intersection (L^0_1) is marked by a prominent pencil structure and lineation, also plunging to the southwest. Second-phase folds (F_2) are located along the northern edge of the quarry. The F_2 folds reorient the F_1 fold axes and L^0_1 lineations, plunge steeply to the east, and share an '**S**' asymmetry. They appear related to movement along the O'Neil Fault, which, if true, indicates a sinistral phase of strike-slip motion on the structure. Albertite, a solid black bitumen, occurs in bedding-parallel veins with slickensides in an F_2 fold closure immediately adjacent to the O'Neil Fault. Albertite also appears with barite, calcite, and fluorite in late northwest-trending vertical fractures that cut all earlier folds and related fabrics.

The dip and aggregate displacement on the O'Neil Fault are not well constrained. The cleavage in the reddish brown mudstones of the McQuade Brook Formation, and the cleavage and steeply plunging F_2 folds in the Albert Formation, if coplanar with the fault surface, indicate a steeply dipping structure. Both the McQuade Brook and Albert formations regionally dip and face southeasterly and are in their expected or 'normal' depositional order, making it unlikely that a significant section is missing across the fault.

North River Fault

The North River Fault (Norman 1941b; St. Peter 2006a; Park and St. Peter 2009) is the most significant structure in the IMDZ. The fault defines the southeastern margin of the Cocagne Subbasin with the Westmorland Uplift in the Indian Mountain area (Fig. 10, 84, 85). This northeast-trending break transects the IMDZ longitudinally and can be traced as a subtle lineament along the valleys of North River and Shediac River (Plate 3). As mentioned above, it defines the boundary between a southeast-facing panel of Horton rocks on the north and a block of crystalline basement with a cover of local Horton inliers and a thick succession of Sussex rocks on the south.

The location of the fault is inferred for most of its length by contrasts in rock units across its trace. However, deformed rocks associated with the fault occur in three locations: 1) along North River south of Pacific Junction, 2) along the upper part of North River about 1.3 km east of Highway 126, and 3) along Shediac River east of Highway 115. The structural and kinematic evidence at these locations is described in detail by Park and St. Peter (2009).

Shales of the Gautreau Formation crop out along North River south of Pacific Junction (Fig. 10), where they show open folds, folds with box profiles, C–S fabrics, and ramping bedding-parallel shear zones. The small-scale structures exposed in the riverbed dip steeply between 60°S and 70°S, the interpreted orientation of the North River Fault itself. Fold axes are generally oriented downdip. Kinematic indicators such as C–S fabrics, ramping geometry, and fold asymmetry consistently indicate right-lateral strike-slip movement across this zone. The features are interpreted to reflect a larger scale, bedding-parallel shear zone (North River Fault) presumably situated just north of the river exposures. The location of the fault trace in this area is evidenced by the fact that the south or hanging wall carries Gautreau and Briggs Cross formations, whereas the north or footwall holds the Albert Formation.

The trace of the North River Fault on the east side of Highway 126 is interpreted to lie a few tens of metres north of the bed of North River (Plate 3). About 1.3 km east of Highway 126, an outcrop of grey shale of the Albert Formation in the riverbed yielded spores of Tournaisian Zone 2 (spore locality P on Plate 3). However, the presence of the Albert Formation there is out of sequence. For example, the strata immediately north of the grey Albert shale are a south-dipping panel of younger Indian Mountain Formation, whereas the beds to the south represent a south-facing panel of Gautreau Formation (Park and St. Peter 2009). Such lithostratigraphic and biostratigraphic constraints force the conclusion that the grey Albert shale represents a lenticular enclave translated along the North River Fault. Supporting this assumption is the fact that the Albert shale is deformed into steeply plunging, asymmetric, box-profile folds with related fractures. The minor structures indicate the fault is a steep structure, dipping around 80°S. The asymmetry of the folds and related fractures suggest right-lateral, strike-slip motion on the fault zone, analogous to that seen south of Pacific Junction.

Outcrops along Shediac River east of Highway 115 constrain the location of the North River Fault in that area (Fig. 10). Although the fault surface is not exposed, the McQuade Brook Formation on the north is juxtaposed against the Memramcook Formation and Stilesville Formation on the south. The Memramcook beds consistently strike to the northeast, face toward the northwest, and are replaced on the north side of the fault by the McQuade Brook Formation. The magnitude of the North River Fault in this area is shown by the degree and complexity of deformation in the McQuade Brook strata that pervades a band at least 300 m wide on the north side of the fault trace. Within that band are variously oriented and intersecting shears that give rise to breccia zones which, in places, are up to 10 m wide. Outcrops nearest the main fault trace display anastomosing shears and locally a shear cleavage. Slickensides on the shears show both sinistral and dextral senses of displacement. Drag folds in the shear zones are rarely intact and typically consist of preserved hinge zones, parts of hinge zones, or parts of fold limbs. The minor structures in the McQuade Brook rocks in this area imply that the adjacent North River Fault is probably a steeply dipping break with an approximate easterly strike. However, it cannot be conclusively determined whether the main displacement was dextral or sinistral.

Rocks of the Memramcook Formation (interbedded conglomerate and sandstone with minor grey and greyish green shale) are exposed south of the fault and east of Irishtown Road along Shediac River (Fig. 10). Bedding is steep to vertical and youngs to the north. Extensive bedding-parallel deformation in this unit is demonstrated by focused shears along the shaly intervals with horizontal slickensides, and by box-profile folds with steep to vertical plunges. The context suggests these zones are parallel to the North River Fault. Kinematic indicators are somewhat ambiguous but imply a mainly dextral sense of shear.

The zone of highly brecciated and sheared rocks of the McQuade Brook Formation along Shediac River is interpreted to be bounded on its north side by a major northeast-striking splay of the North River Fault. For example, the Indian Mountain Formation occurs on the north side of the road leading to Scotch Settlement Road (Fig. 10), which forces the conclusion that the Albert Formation is faulted out along this part of the splay. The magnitude of displacement on the splay is implied by the local thickness of the Albert Formation, which exceeds 1 km. The paucity of exposure between Shediac River and McQuade Brook precludes an assessment of this splay of the North River Fault. However, the splay is interpreted to itself split into second-order splays that define the boundaries of the fault-bounded panels of the Albert Formation and McQuade Brook Formation at McQuade Brook (Fig. 10).

The preponderance of outcrop evidence suggests that the North River Fault has substantial lateral, and probably mostly right-lateral, displacement. However, significant geometric constraints are imposed by the 3 km thick, south-facing panel of Horton rocks on the north side of the fault, which is in juxtaposition with a massive block of basement on the south side in The Gorge area (Fig. 10). These constraints apparently require the fault to dip to the south and have a reverse component of movement, perhaps as great as 3 km (Fig. 85). A south-over-north displacement on the North River Fault is consistent with the interpreted movement on The Gorge Fault (see below), which subparallels the North River Fault.

Although the North River Fault defines the southeastern margin of the Cocagne Subbasin in the Indian Mountain area (Fig. 10, 84, 85), it represents a structural, not a depositional, boundary of the subbasin. The generally fine-grained lacustrine rocks of the Albert Formation and fining-upward fluvial cycles of the Indian Mountain Formation immediately north of the fault are not basin-margin depositional lithofacies. Clearly, the southeastern depositional margin of the Cocagne Subbasin is missing. Whether it was translated laterally and later buried beneath younger Carboniferous rocks to the northeast (?) or was uplifted on the Westmorland basement block and eroded before deposition of the Sussex Group is not certain. The fault-bounded outlier of Memramcook Formation on the south side of the North River Fault near Irishtown (Fig. 10) and the ubiquitous early Tournaisian spores in late Tournaisian Sussex rocks make a strong case for uplift and erosion.

Finally, the major displacement of the basement against the Horton Group (Fig. 85) demonstrates that most of the reverse south-over-north movement on the North River Fault was a post-Horton event. Offset also occurred on the fault following deposition of the Sussex Group. The later movement appears to have a down-to-the-southeast 'normal' component as evidenced by the juxtaposition of Sussex units on the south side of the fault against Horton units on the north side along most of the fault trace (Fig. 85; Plate 3).

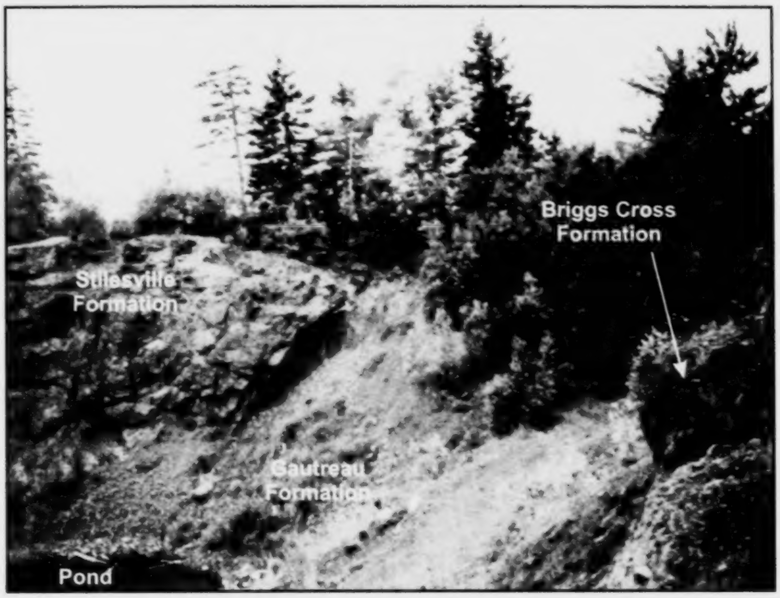
The Gorge Fault

The Gorge Fault is the most recognizable displacement in the IMDZ. Gussow (1953, his Fig. 9, section K–L) named it 'Lutes Mountain Fault.' Because the structure does not in fact occur at Lutes Mountain, it was subsequently renamed 'The Gorge Fault' after The Gorge (Fig. 10) where it is exposed (St. Peter 1995b, 1995c, 2006a). The fault elevates quarriable basement granitoid rocks on the southeast, hanging-wall side of the break, against Sussex rocks on the footwall side (Fig. 85; Plate 3). This displacement has been used to advantage by quarry workers for decades (Gussow 1953; Carr 1968). The fault is well exposed in two quarries at The Gorge: the abandoned Tri-Gil quarry and the larger, active Moncton Crushed Stone quarry (Fig. 10, 85).

Tri-Gil Quarry: A unit of Stilesville Formation comprising a basal regolith immediately overlies the basement rocks on the north side of the Tri-Gil quarry. The regolith is capped by breccias, the clasts of which are undoubtedly derived from the local crystalline basement. The Stilesville breccia is about 40 m thick in the northwest corner of the quarry and about 12 m thick on the east side (St. Peter 2006a, his Fig. 41). The north side of the Stilesville Formation there marks the trace of The Gorge Fault, which dips moderately steeply to the south on the northwest side of the pit (Fig. 86). The fault on the east quarry wall strikes 70°, dips 80°N, and shows two generations of slickensides: an early set pitching 40°NW and a later set pitching 10°NE. These measurements imply early oblique slip and later lateral slip. Shears occur in a zone 30 cm to 60 cm south of the main fault surface. They lie parallel to the main fault and display steeply pitching slickensides. Presumably, the slickensides predate those on the main fault surface and, if so, indicate an early dip-slip sense of displacement and a prolonged and multiple-movement history for The Gorge Fault.

The north, footwall side of The Gorge Fault in the quarry comprises a highly attenuated unit of reddish brown tectonic mudstone mélange of the Gautreau Formation, which locally carries rounded knockers of more competent sandstone. The Gautreau is concordantly succeeded by a north-facing and overturned sequence of the Briggs Cross Formation comprising interstratified polymictic conglomerates, sandstones, reddish brown mudstones, and minor grey shale. The Briggs Cross Formation shows evidence of synsedimentary foundering in the form of ball-and-pillow structures, some of which were modified by later F_1 tectonic folds. The north-facing panel of Gautreau and Briggs Cross strata is interpreted to represent the south limb of an overturned footwall syncline, the axis of which lies north of the quarry (Fig. 85). The footwall syncline is apparently overridden by splays of The Gorge Fault northeast of the

Figure 86. The Gorge Fault (dashed line), northwest corner of the Tri-Gil quarry (Fig. 10). Megabreccia with basement blocks of the Stilesville Formation form the hanging wall; highly deformed red shale and siltstone of the Gautreau Formation form the footwall. The Gautreau Formation is overlain by conglomerate of the Briggs Cross Formation (right foreground).



quarry at about the location where the fault crosses Gorge Road. The syncline re-emerges northeast of the Moncton Crushed Stone quarry (Fig. 10), where it is cored by the Gautreau Formation just north of the splay of The Gorge Fault that carries the exhumed basement slice. The trace of The Gorge Fault along the north side of the Tri-Gil quarry is offset by steeply dipping, northwest-striking cross faults that break the north wall of the quarry section into fault panels that preserve different structural levels (see Park and St. Peter 2009 for more details).

Moncton Crushed Stone Quarry: In the Moncton Crushed Stone quarry, several steep to moderately south-dipping reverse faults are best displayed along the north side of the quarry. In each case the faults, which are splays of The Gorge Fault system, carry basement rocks in their hanging walls and sedimentary rocks of the Stilesville and Gautreau formations (both Sussex Group) in their footwalls. Deformation is marked in all quarry rocks by extreme partitioning of strain into particular units. Basement rocks away from the main reverse faults are largely undeformed, but the fault zones feature brecciation, phyllitic alteration, and foliation development. In the overlying Sussex rocks, shale layers and partings take up most of the strain; intensely folded layers appear side by side with siltstone and sandstone units carrying perfectly preserved sedimentary structures.

Folds fall into two generations, resulting in a wide scatter of bedding orientations. All early (F_1) folds are geometrically related to the reverse faults, forming hanging-wall and footwall antiforms and synforms, or antiforms above fault tips. (The overridden syncline noted above in the Tri-Gil quarry is apparently an example of a larger scale footwall (F_1) syncline (Fig. 85).) Folds in the Moncton Crushed Stone quarry typically have strongly curvilinear hinge lines and can die out completely over distances of 50 m to 100 m. The overall vergence and asymmetry of these folds conform with the movement sense on the reverse faults, indicating top-to-the-north or -northwest. Bedding-parallel slip is also evident, especially on lithological contacts between rock types of strongly contrasted competence. Here, rheoplastic features are common, especially around large clasts where mudtails form a prominent lineation. Related folds in sandstone–siltstone layers are typically tight to isoclinal but carry no evidence of brittle

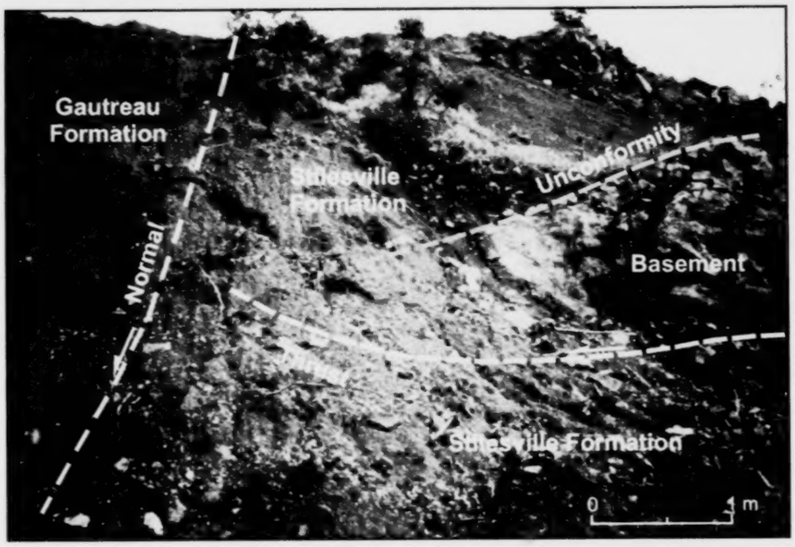
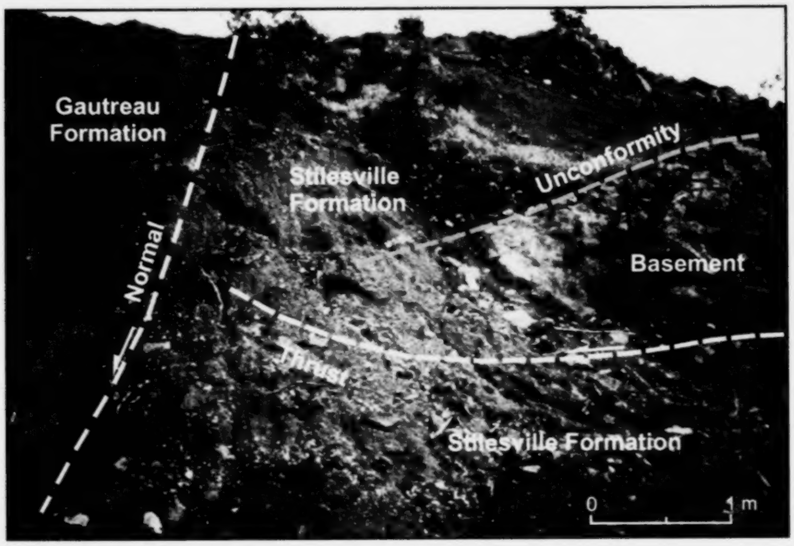


Figure 87. Structural features in the western end of the Moncton Crushed Stone quarry (Fig. 10). An F_1-related thrust with basement forms the hanging wall, and the Stilesville Formation forms the footwall. The thrust is offset by a post-F_1 normal fault that brings the Gautreau Formation down in the hanging wall.

fracturing. These two features indicate that the more competent units were still plastic while undergoing deformation, suggesting that the Sussex rocks had not completely dewatered when F_1 folding occurred.

F_2 folds have a very restricted occurrence in the northwest part of the Moncton Crushed Stone quarry, where a clear overprinting relationship with the F_1 folds is apparent. The F_2 folds are open to tight features with axes that plunge variously from vertical to 50°ENE. Their vergence and asymmetry are consistently '**S**' type, suggesting a relationship to a left-lateral displacement along an unexposed splay of The Gorge Fault, one interpreted to lie immediately north of the quarry. A series of north-, northwest-, and northeast-trending faults cross the quarry. Where relationships to the early reverse faults and F_1 folds can be demonstrated, these faults can be identified as later structures (Fig. 87). Their relationship to the F_2 folds could not be determined. All are normal faults and display downthrow to the east, west, and north. The outcrop pattern is further complicated by the presence of southward-verging thrusts that bring basement rock over the Stilesville Formation, and that locally cross-cut the northward-verging thrusts.

The geometrical interpretation of The Gorge Fault system to emerge from examinations of the Tri-Gil and Moncton Crushed Stone quarries is of a major southeast-dipping dislocation that forms a single trace southwest of the Tri-Gil quarry, but that splits into several subparallel splays northeast of there (Fig. 10, 85). The splays reconverge farther to the northeast where The Gorge Fault is eventually cut off by the North River Fault on the west side of Highway 490 (Fig. 10). Early displacement on The Gorge Fault was largely compressional, in which the hanging wall comprising basement and indurated breccia of the Stilesville Formation was reverse- or thrust-faulted over less competent rocks of the Sussex Group that are characterized by mélange zones and footwall synclines. Steeply plunging F_2 folds in the Moncton Crushed Stone quarry and subhorizontal slickensides on the main fault trace in the Tri-Gil quarry attest to a phase of left-lateral displacement on The Gorge Fault system. Less significant and later northwest- to northeast-striking cross faults offset the various splays, further complicating the final geometry (Park and St. Peter 2009).



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As noted in Chapter 2, the Stilesville and Gautreau formations lie in undisturbed depositional contact on granitoid basement rocks on the south side of the basement block exposed at the Tri-Gil and Moncton Crushed Stone quarries (Fig. 10). This relationship is critical with respect to determining what displacement is attributable to The Gorge Fault. Gussow (1953) and Webb (1963) believed that the Memramcook Formation overlay the south side of the basement inlier at The Gorge. Consequently, their interpretation required the basement block to be faulted up through the Memramcook and Albert formations to achieve its present position in juxtaposition with the Sussex Group on its north side. Because the basement in this area is overlain by the Sussex Group and not the Memramcook Formation, far less displacement is needed on The Gorge Fault to achieve the present map configuration. The interpretation here (Fig. 85) suggests that a vertical displacement on The Gorge Fault of perhaps 400 m or 500 m is sufficient to produce the map pattern. The North River Fault, not The Gorge Fault, is obviously the major compressional break inside the IMDZ.

Salt Springs Brook Fault

The Salt Springs Brook Fault in the IMDZ lies subparallel to the major Berry Mills Fault. It extends from Ammon (Fig. 10; Plate 3) southwestward for about 35 km to Salt Springs Brook (St. Peter 2006a), where it was first recognized but unnamed by Stewart (1941a–1941c). The following section summarizes the location and history of movement along the fault as detailed in and interpreted by Park and St. Peter (2009).

About 1.5 km northwest of Magnetic Hill and 2 km northeast of Lutes Mountain (Fig. 10; Plate 3), outcrops along road ditches (46°08'51.5"N; 64°53'30.9"W) reveal the approximate trace of the Salt Springs Brook Fault. There, conglomerates, sandstones, and minor mudrocks of the Stilesville Formation on the south side of the fault are sheared against massive conglomerate of the Briggs Cross Formation on the north side of the structure. Movement on the Salt Springs Brook Fault is indicated by multiple, very steeply dipping shear zones focused in the siltstone–mudstone intervals of the Stilesville Formation adjacent to the concealed fault trace. The sheared mudstones carry lenticular and rounded tectonic knockers of sandstone that apparently were calved off adjacent sandstone beds. Slickensides on shear surfaces in the mudstones show two main orientations (Fig. 88). In one shear zone with a strike of 30° and a dip of 90°, the slickensides pitch 70°NE; on another shear zone with a strike of 40° and a dip of 90°, the slickensides are subhorizontal. An unequivocal interpretation of the sense of offset could not be determined from the slickensides, but the Salt Springs Brook Fault, at least in that location, seems to be a steep structure with a history of both dip-slip and strike-slip movement.

The location of the Salt Springs Brook Fault is also evidenced on the high ground about 400 m northeast of the foregoing locality, where an elongate and lenticular northeast-striking wedge of reddish brown and lesser olive green mudstones and sandstone lies in the fault zone. The rock wedge is interpreted as Gautreau Formation. Bedding in the Gautreau strata dip vertically, face to the northwest, and strike about 40° to 50°. They thus lie discordantly with respect to adjacent beds in either the Stilesville Formation on the southeast or the Briggs Cross Formation on the northwest (Plate 3). The faulted boundaries of the wedge are not exposed, making it impossible to assess whether the wedge was uplifted from beneath the Briggs Cross Formation to the north via dip slip or translated from the exhumed Gautreau on

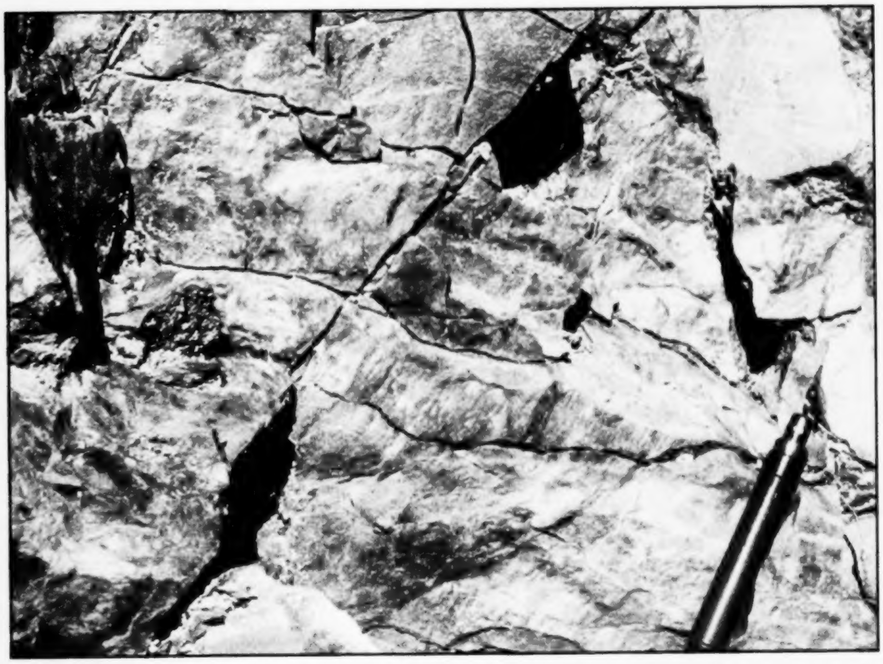

Figure 88. Steeply plunging slickensides (parallel to pen) on shear surfaces in reddish brown mudstone of the Stilesville Formation, Lutes Mountain, adjacent to the Salt Springs Brook Fault (Fig. 10).

the southwest side of the fault at Lutes Mountain via dextral strike slip. Both dip-slip and strike-slip displacements can be demonstrated on the Salt Springs Brook Fault, suggesting that the Gautreau wedge may have been emplaced by a summation of movements.

The large Dexter Construction quarry on the east side of Gorge Road (Fig. 10, 85) is located near the point of divergence of two splays of the Salt Springs Brook Fault. The more northern splay strikes northeast and bypasses the pit, whereas the more southern splay trends east-northeast and passes through the quarry. The northern splay is exposed in the rock cut facing Gorge Road adjacent to the Dexter quarry, appearing as a steep northwest-dipping surface. The surface shows slickensides pitching 45°SW, which implies oblique movement on the splay. The splay location and orientation are spatially consistent with the regional trend of the main fault trace.

The sense of displacement on the northern splay is interpreted to be largely dextral, as inferred from two lines of evidence. First, the strikes of the Briggs Cross and Gautreau formations change from approximately east–west around the Briggs Cross type section to southeasterly immediately west of Gorge Road. This suggests the presence of a major drag fold in the northwestern block associated with right-lateral offset on the fault. Second, a thick, west-dipping panel of Stilesville Formation faces a block of exposed basement to the west on the south side of the fault west of Ammon. This is analogous to the thick, west-dipping panel of Stilesville Formation facing the basement in the Moncton Crushed Stone quarry on the north side of the fault. The relationship of the Stilesville Formation to the basement on either side of the fault implies a right-lateral offset. The interpreted dextral offset on the northern splay is consistent with and complements the west-over-east thrust displacement shown by the narrow basement slice overriding the Stilesville Formation north of Ammon (Fig. 10; Plate 3).

The southern splay splits from the main Salt Springs Brook Fault at Gorge Road and from there tracks east-northeasterly through the axial part of the Dexter Construction quarry. An east-trending wedge of Gautreau Formation in the quarry is truncated by this southern splay, which is a south-dipping thrust carrying highly indurated cobble to boulder conglomerate of the Stilesville Formation in its hanging wall. A syncline occurs in the hanging-wall block and has a northeast-trending axis discernable from Lutes Mountain northeastward to the Dexter quarry (Fig. 10). In the eastern part of the quarry, the synclinal axis is cut off by the Salt Springs Brook Fault (Plate 3). Southwest of the quarry, beds on the north synclinal limb apparently underwent counterclockwise rotation in proximity to the main trace of the Salt Springs Brook Fault, suggesting a sinistral component of movement on the fault. Such a sinistral displacement along this, the main northeast-trending part of the fault, is consistent with the demonstrable thrust geometry determined for the east-northeast-striking southern splay in the quarry.

Displacement on the Salt Springs Brook Fault occurred later than deposition of the Sussex Group. How much later is not well known. In the Salisbury area 20 km southwest of The Gorge (Fig. 6), St. Peter (2006a, his Fig. 5) interpreted the fault as covered by the late Westphalian B to early Westphalian C Salisbury Formation. Poor exposure there leaves the interpretation tentative, and it is possible the fault may share some post-Westphalian D movement with the parallel Berry Mills Fault.

Berry Mills Fault

The Berry Mills Fault defines the southeastern boundary of the IMDZ within the Westmorland Uplift (Fig. 6, 84, 85). This regionally significant structure has been delineated for more than 80 km from Sussex (Fig. 6) northeastward to McQuade Brook (Fig. 10; Gussow 1953; St. Peter 2006a). Gussow (1953) recognized the magnitude of the break and cited geological, topographical, and seismic evidence to support its location. He interpreted it as a steeply northwest-dipping compressional structure, an interpretation agreed with by St. Peter (2006a). However, a re-examination by Park and St. Peter (2009) of the geological data and seismic reflection profiles suggests this interpretation may be in error. As a result, they propose a refinement of the surface location of the Berry Mills Fault in the report area from that postulated by earlier workers (e.g, Gussow 1953; St. Peter 1989b, 1995a–1995c). The following summary is from Park and St. Peter (2009).

Between Magnetic Hill and Gorge Road, two sandstone outcrops of the Richibucto Formation are exposed only metres from conglomerate outcrops of the Stilesville Formation, demonstrating that the formational boundary in this area is an undisturbed unconformity (Plate 3). The Richibucto Formation is therefore interpreted to lie on the northwest, footwall side of the Berry Mills Fault. Farther to the northeast along Shediac River (Fig. 10), the fault trace is closely constrained by outcrops of the Richibucto Formation. A significant increase in dip of the beds is observed as the fault trace is approached. About 1 km southeast of the fault, the beds along the river are horizontal, whereas immediately adjacent to the fault trace they dip 70°SE. This increase in dip of beds on the southeast side of the fault is repeated farther northeast in the section along McQuade Brook, where the beds dip vertically within metres of the fault trace.

Gussow (1953; his cross-section K–L) provides some evidence that the Berry Mills Fault dips to the southeast. His report describes a water well (Harrisland well) drilled just south of the surface fault trace at The Gorge; the well cut the Richibucto Formation from surface to the end-of-hole at 224 m. The thickness of the Richibucto section in the well compared with the shallow southeastern dip of the surface section immediately to the north (where the basal Richibucto rests unconformably on the Stilesville Formation) requires a structural break, in which the southeastern block (the block 'containing' the well) moved down in post-Richibucto time.

Seismic reflection profiles crossing the fault trace demonstrate that the Berry Mills Fault dips steeply, most likely toward the southeast. Park and St. Peter (2009, their Fig. 41) show one such line, part of the Chevron Standard Ltd. seismic line 79Y shot in 1981 along Highway 490. On that profile, the basement–cover boundary (at 700–800 milliseconds two-way-time) and the shallowly dipping Carboniferous beds above it appear to be truncated by the Berry Mills Fault. Control on the location and dip of the fault on the profile is provided by 1) a very close fix on the surface position of the fault trace, 2) an abrupt termination of the basement–cover reflector and the overlying more subtle 'Carboniferous' reflectors, and 3) the apparent upward rotation of those reflectors adjacent to the fault.

It is concluded from surface geological evidence and an interpretation of seismic data that the Berry Mills Fault had a substantial down-to-the-south, dip-slip, extensional or transtensional component of movement in post-Pictou (post-Stephanian) time. The interpretation herein (Fig. 85) shows a possible dip-slip movement of about 800 m on the contact at the base of the Pictou Group. In contrast, the total displacement on the basement is approximately 1800 m. The timing on the pre-Pictou offset is not well known. The apparent absence of Horton and Sussex rocks, even on the buried Westmorland Uplift block on the south side of the Berry Mills Fault (Fig. 85), suggests that part of the uplift remained 'high' until Windsor time. Thus, the basement offset is likely a post-Windsor event. In its early history, the Berry Mills Fault may have been a compressional fault in which the north side moved up. In this case, only the later post-Pictou reactivation would have been extensional and involved the south side dropping. Under such a scenario, the movement history of the Berry Mills Fault may be analogous to that interpreted for the North River Fault.

Summary, Indian Mountain Deformed Zone Structure

The ultimate configuration of the IMDZ is a consequence of several tectonic events. It is not a 'structure' resulting from a single phase of thrusting (Gussow 1953), strike slip (Webb 1963 1969), or rifting (Belt 1968). The inversion that followed Horton deposition was accomplished with a substantial compressional component, as evidenced by the north-vergent displacement of basement rocks over Horton rocks along the North River Fault. South-over-north (mainly) offsets on faults affecting the Sussex Group, such as The Gorge and Salt Springs Brook faults, indicate a second compressional phase of tectonism. The timing on this second 'push' may reflect termination of the Sussex depositional cycle or the more significant event represented by the interregional Mississippian–Pennsylvanian unconformity between the Mabou and Cumberland groups.

Questions still remain on the timing and amount of lateral displacement on the major faults. Sinistral movement on The Gorge, O'Neil, and Salt Springs Brook breaks, as well as dextral movement on the North River and Salt Springs Brook structures, has been demonstrated herein and elsewhere. Opposing sinistral and dextral senses of translation on the Salt Springs Brook Fault, which offsets the Sussex Group but not the exhumed Horton Group in the report area, show that both senses of translations reflect events that, at least in part, postdated the Sussex Group. Accordingly, tectonism that ended deposition of the Horton Group may not have been accompanied by much if any strike-slip movement in the IMDZ. The late displacement affecting the Belleisle, Smith Creek, and Berry Mills faults was apparently mainly extensional.

EASTERN MONCTON SUBBASIN STRUCTURE

This section focuses on structures in the eastern Moncton Subbasin from Parkindale eastward to Memramcook, specifically those responsible for creating accommodation space and subsequently inverting the basin following deposition of the Horton, Sussex, Windsor and Mabou groups. The most important northeast-trending structures in this category are the Gaytons, Gordon Falls, Pollett River, Gowland Mountain, Prosser Mountain, Caledonia, Saint-Joseph, Salem, Edgetts Landing, Dorchester, and Wilson Brook faults (Fig. 84; Plate 4). This section includes a brief account of the Weldon Syncline just west of Weldon and concludes with a summary of the northwest-trending faults, which have played a subordinate role in sedimentation and displacement of the basin fill.

Gaytons Fault

The Gaytons Fault is the only exposed easterly trending fault known to define part of the boundary between the Westmorland Uplift and the Moncton Subbasin (Fig. 11, 84; Plate 3). It has not been established whether the fault is offset by and continues east of the Memramcook East Fault (Fig. 84). Accordingly, it is unclear whether the southern boundary of the basement exposed at Prairie Brook (Plate 3) is faulted or unbroken.

Gussow (1953, his Fig. 5) noted the Gaytons Fault but offered no description. The fault was named and interpreted as a north-dipping reverse structure by St. Peter (1992) on the basis of evidence from the Modern Construction (1987) Ltd. quarry in basement granite on the east side of Memramcook River at Gaytons (Fig. 11). The following description was written in 1990, but because the quarry has been continuously active since that date, it is doubtful that the contact relationships described herein are still preserved.

The single fault line on Figure 11 is an oversimplification of the Gaytons Fault. The line denotes the general trend of the late displacement on the fault zone. On the south quarry wall, this displacement is a break between megacrystic granite on the north, reverse-faulted against thick-bedded polymictic conglomerate, grit, and minor sandstone, and mudstone of the Memramcook Formation on the south. The attitude of that late displacement strikes 80° and dips 80°N. Three sets of slickensides occur on the fault surface: two with shallow pitches and one, apparently the latest, pitching 80°NNW. The late north-over-south reverse movement raising the basement over the basin presumably represents most of the movement on the Gaytons Fault. The late fault cuts an earlier fault in the south quarry wall. The early fault is also a reverse structure but strikes 35° and dips 40°SE. It carries a steeply dipping, interbedded panel of sandstones and mudstones of the Memramcook Formation over footwall granite. In other words, the inversion of the Memramcook Formation against the Westmorland basement block appears to have taken place via at least two phases of movement: an early north-vergent push and a later south-directed push.

Outcrop is not sufficiently plentiful to map the relationships among formations in the Gaytons area with a high degree of confidence. However, the Boss Point Formation appears to overlie all units, including the Gaytons Fault, indicating that the fault has been dormant since the mid-Namurian unconformity.

Gordon Falls Fault

The Gordon Falls Fault occurs in the westernmost part of the report area and continues westward, where it locally defines a boundary between the Caledonia Uplift and Moncton Subbasin (Fig. 6, 84). Its trace can be followed from Little River just north of Parkindale southwest for 15 km to Upper Goshen (Park et al. 2007, their Fig. 3). The fault is exposed nowhere. However, just north of Gordon Falls on Pollett River, about 2 km south of Elgin (Fig. 6), a 50 m wide concealed interval hides a contact between the basement on the south and the Memramcook Formation on the north. A poor exposure of Memramcook Formation on a secondary road 2 km east of Elgin reveals a shaly gouge showing a north-side-down, dip-slip movement (Park et al. 2007). A down-to-the-north displacement supports the evidence cited by St. Peter (1992) from an interpreted seismic reflection line that crosses the fault trace 1.8 km west of Little River. The presence of polymictic pebble to boulder conglomerate of the Memramcook Formation along the north side of the fault trace suggests the Gordon Falls Fault became active in early Horton time and was one of the extensional or transtensional structures controlling subsidence along the southeast side of the Moncton Subbasin.

Pollett River Fault

The Pollett River Fault (Fig. 84) also lies in the westernmost part of the report area and continues westward of Plate 4. The fault has a northeasterly strike and lies parallel to and less than 1 km north of the Gordon Falls Fault (St. Peter 1989b, 1992; Park et al. 2007). The fault line is evident from discordant bedding in the Memramcook and Albert formations for 15 km along its strike (St. Peter 1989b). It is exposed along Pollett River south of Elgin where conglomerate of the Memramcook Formation is juxtaposed against conglomerate of the Albert Formation. The Memramcook beds dip shallowly to the southeast, whereas the Albert strata dip steeply or are overturned and face northwest. Kinematic indicators in the Memramcook Formation give ambiguous senses of displacement from dip slip to both right- and left-lateral strike slip (Park et al. 2007). Reverse south-over-north movement is indicated on the Pollett River Fault by overturned northwest-facing beds of Albert Formation adjacent to the fault at three points along its trace (St. Peter 1992, p. 91). Older Memramcook and McQuade Brook formations on the south side of the fault indicate the south side has moved up relative to the Albert Formation on the north (Gussow 1953, p. 1775). The Pollett River and Gordon Falls faults merge at Little River (Plate 4). Their mutual trace east of the river does not apparently offset the Boss Point Formation, indicating that the latest displacement on both faults predates the mid-Namurian unconformity between the Mabou and Cumberland groups.

St. Peter (1992, 1993) and Park et al. (2007) make the case that the Gordon Falls Fault, Pollett River Fault, and related faults in the Elgin area represent a right-lateral, strike-slip duplex. The presence of right-handed megascopic folds (see Wilcox et al. 1973 for fold definitions) in the Memramcook Formation between the Gordon Falls and Pollett River faults at Pollett River, in the Round Hill Formation west of Elgin, and in the Albert Formation south of Parkindale (Plate 4) are all consistent with dextral transpression. Also, the Albert and Round Hill formations on the north side of the Pollett River Fault consistently strike more northerly than the fault trace, which suggests oblique translation. Exhumation of Horton and Sussex rocks along the Caledonia basement from Goshen to Parkindale demonstrates inversion of the succession. The Lee Brook Fault, Elgin Fault, and intervening anticline in the Round Hill Formation west of Elgin (Park et al. 2007, their Fig. 3) are all overstepped by an unconformity at the base of the Hillsborough Formation (Windsor Group). The relationships suggest that the inversion–transpression took place at the end of the Tournaisian and thus terminated deposition of the Sussex Group (Park et al. 2007).

Gowland Mountain Fault

The Gowland Mountain Fault (Fig. 84) was first mapped by Gussow (1953, p. 1775) as the 'Coverdale Fault' and later renamed (by Popper 1965) the 'Gowland Mountain Fault.' It exists as two splays west of Sweet Mountain. The western splay defines the boundary between polymictic conglomerates and sandstones of the Memramcook Formation and mudstones and sandstones of the McQuade Brook Formation (Plate 4). Only the western splay was identified by Gussow (1953), Popper (1965), and St. Peter (1989b). The eastern splay marks the boundary between crystalline rocks at Sweet Mountain on the southeast and mudstones and sandstones of the McQuade Brook Formation on the northwest (Plate 4). The two splays apparently converge at Mount Zackie Jonah about 3 km southwest of where the splays cross Little River. At Mount Zackie Jonah, a small outlier of vertically dipping, fine-grained redbeds of the McQuade Brook Formation indicates the approximate location of the fault line (Stewart 1941c; Popper 1965).

The western and eastern splays are not exposed but are interpreted to exist on the basis of map relationships. The location of the western splay is estimated to be where east-facing beds of the Memramcook Formation abut northwest-dipping beds of the McQuade Brook Formation. As well, the Memramcook beds dip more steeply near the fault trace. The existence of the eastern splay is suggested by the absence of the Memramcook Formation from its expected stratigraphic position between the basement and McQuade Brook Formation. Also, the McQuade Brook beds become progressively more steeply dipping closer to the interpreted fault trace. Juxtaposition of the McQuade Brook Formation against the basement provides evidence that the northwest side of the fault has moved downward.

The presence of the younger McQuade Brook Formation on the southeast side of the fault suggests a down-to-the-southeast component of movement. Gussow (1953, his Fig. 5) interpreted the structure as a southeast-dipping reverse fault, apparently assuming (as was believed at the time) that rocks on the southeast were Memramcook Formation and those on the northwest were Albert Formation. Popper (1965) argued for right-lateral slip on the western splay. He cited the juxtaposition of a basin-edge facies, represented by the coarse Memramcook Formation of his usage, against a basinward facies, represented by the fine

McQuade Brook Formation (fine-grained Memramcook Formation of his usage), as evidence that the coarse Memramcook Formation probably moved to the right, farther out in the basin. However, because the McQuade Brook Formation lies stratigraphically above the Memramcook Formation in this area (a point not entirely appreciated by Popper: e.g., see the relationship north of Ferndale), strike-slip motion is not required to achieve the resultant geometry. Even though right-lateral movement remains unproven, the Gowland Mountain Fault may share dextral displacement with the other more northern faults in the duplex. The western splay is cut off and offset by the Gordon Falls Fault just east of Little River (Plate 4).

The timing of displacement on the splays of the Gowland Mountain Fault is not well constrained. The youngest affected unit is the early Tournaisian McQuade Brook Formation. The eastern splay and the Gordon Falls Fault are both overstepped by the unaffected Boss Point Formation.

Prosser Mountain Fault

The Prosser Mountain Fault (Fig. 84) locally defines a boundary between the Caledonia Uplift and the Moncton Subbasin. It is one of the most recognizable faults in southeastern New Brunswick because of its straight and obvious topographic escarpment formed by the basement cliffs at Sweet Mountain (Park et al. 2007, their Fig. 10; Plate 4). Norman (1941a) first recognized the fault. Gussow (1953, his Fig. 5, 11) named it and drafted it as a reverse or thrust fault carrying basement on the northwest over the Hillsborough Formation on the southeast. St. Peter (1989b, 1992) also interprets the Prosser Mountain Fault as a compressional structure and believes it to be a fairly steep, northwest-dipping reverse break.

The fault surface between basement and the Hillsborough Formation is not exposed. However, an excellent section of basement granodiorite and amphibolite occurs along the road at Prosser Brook just metres from the fault trace and provides an appreciation of the fault orientation and kinematics. The outcrop is figured and described in some detail in Park et al. (2007, their Fig. 9a). A prominent set of faults appears in the section; the faults have a northeast strike and dip 50° to 70°NW. Slickensides on the faults show a shear sense with top-to-the-southeast or -east, suggesting the fault is a steep, northwest-dipping reverse fault with an oblique right-lateral component of movement (Park et al. 2007).

Timing on the Prosser Mountain break is constrained by the post-early Visean displacement of the Hillsborough Formation and the apparent absence of offset on the unconformably overlying late Namurian–early Westphalian Boss Point Formation (Plate 4). The absence of a thick section of rocks (proximal or otherwise) of either the Horton or Sussex group on the southeast side of the break indirectly implies that the Prosser Mountain Fault was probably not an important structure in the early depositional history of the Moncton Subbasin.

Caledonia Fault

The Caledonia Fault (Fig. 84) was first recognized by Gussow (1953) as a major break defining the boundary between the Caledonia Uplift and Moncton Subbasin from Prosser Brook northeastward to Frederick Brook, a distance of about 20 km (Plate 4). He interpreted it as a northwest-dipping reverse or thrust fault and as the main dislocation that inverted the

Horton and Sussex groups along the southeastern margin of the Moncton Subbasin (Gussow 1953, his Fig. 5, 11). St. Peter (1992) added support to Gussow's interpretation by noting a shear zone in mudstones of the Albert Formation within metres of the fault trace about 3 km west of Rosevale. The shear zone strikes approximately east–west, dips 65°N, and bears slickensides pitching 80°E. The north-over-south inversion of the Albert against the basement may account for the absence of the Memramcook and McQuade Brook formations along the basement contact in this area, despite their known presence in Well 200 at Rosevale below a depth of 631 m. Park et al. (2007, their Fig. 6, 14) furthered the argument by documenting rootless slices of basement within the Albert Formation just north of the main fault trace at Lewis Mountain.

The Albert Formation from Prosser Brook to Caledonia Mountain strikes obliquely to the trace of the Caledonia Fault. An analysis of bedding attitudes reveals the presence of mesoscopic folds with axes that trend more northerly than the fault trace (St. Peter 1989a). These right-handed folds imply a dextral component of movement on the inversion. Gussow (1953, p. 1776) assessed the resultant geometry in the following words: "stresses have acted at an angle to the Caledonia massif."

The lithofacies architecture in the Albert Formation (Horton Group) and the proximal polymictic conglomerates of the Round Hill Formation (Sussex Group) lying along the north side of the Caledonia Fault provide evidence of extensional phases of displacement on the fault. Cobble and boulder conglomerates interstratified with oil shale, and containing ripped-up clasts of lacustrine oil shale, within metres of the fault line at Stuart Brook and Rosevale denote the existence of a syn-Albert escarpment. The extrabasinal clasts in the Albert alluvial conglomerates are from the adjacent Caledonia Uplift, which places the basement and basin in close proximity during Horton time.

The existence of rootless slices of basement in the Albert Formation north of Lewis Mountain demands the former presence of a basin-bounding extensional fault that dipped more steeply than the later short-cut thrusts (Park et al. 2007, their Fig. 6, 14). Clasts up to boulder size in the Round Hill Formation are dominated by metavolcanic, metasedimentary, and subordinate plutonic detritus from the Caledonia block and suggest that the Caledonia Fault — again, in Sussex time — was responsible for the relief necessary to build the fan of the Round Hill Formation.

The interpretation herein of the Caledonia Fault and adjacent northeast-trending faults in the eastern Moncton Subbasin (Fig. 14) is based on surface geology, well intersections, and publicly available seismic reflection profiles. The interpretation becomes quite speculative south of Well 333, located 5 km southwest of Hillsborough. The Caledonia, Saint-Joseph, Edgetts Landing, and Dorchester faults are all interpreted as northwest-dipping structures possibly converging at depth and rooted in a single displacement zone passing through the lower part of Well 333. Thus, the anomalously thick Dawson Settlement Member of the Albert Formation in the well is accounted for by a structurally repeated section. The cross-section shows a late down-to-the-north displacement on the Caledonia Fault at Frederick Brook, where the Round Hill Formation on the north is juxtaposed against the Albert Formation on the south (Plate 4). An alternative interpretation could be that the fault has a component of right-lateral offset in this area.

The trace of the Caledonia Fault cannot be followed with confidence east of Frederick Brook. It terminates against a northwest-trending cross fault that drops conglomerate of the Round Hill Formation on the east against oil shale of the Albert Formation on the west. The Caledonia Fault may step to the south on that cross fault where it converges with the Edgetts Landing Fault at depth and thus is buried below the unconformably overlying Windsor Group. Further to this, the Albert Formation is faulted over the Round Hill Formation at a depth of 651 m in Well 318, just southeast of Hillsborough. The Albert is reverse-faulted over the Round Hill Formation on the east side of Petitcodiac River in the section at Boudreau Village (see ***Round Hill Formation*** in Chapter 2). The fault in Well 318 and at Boudreau Village may represent the eastern continuation of the Caledonia Fault. The break in the Boudreau Village section is labelled the 'Caledonia Fault' by Park and St. Peter (2005, their Fig. 11b).

The Caledonia Fault has undergone a protracted history of movement. It is interpreted to have experienced two periods of extensional or transtensional movement during the inception and growth of the Horton and Sussex depositional cycles and two periods of contractional or transpressive displacement during the inversion of the Horton and Sussex groups. The map relationships (Plate 4) indicate the Caledonia Fault does not offset the Hillsborough Formation, which implies the fault was dormant after inversion of the Sussex Group.

Saint-Joseph Fault

The Saint-Joseph Fault (the Hillsborough Fault of Gussow 1953) represents a major splay of the Caledonia Fault within the Moncton Subbasin. The Saint-Joseph Fault is a northwest-dipping reverse structure (Fig. 14, 84) that can be defined on the basis of exposed geological relationships between Caledonia Mountain and Memramcook. Southwest of Salem on the north flank of Round Hill and along Weldon Creek, the location of the break is shown by differing dip measurements. Specifically, conglomerate of the Round Hill Formation on the south side of the fault dips at 20° to 40°S, whereas the adjacent Gautreau and Weldon formations on the north side dip 35° to 50°NW (Plate 4; St. Peter 1989b).

Wright (1922, his Map 68A) first recognized the Saint-Joseph Fault, as defined herein, west of Hillsborough. There, the normally shallowly disposed Hillsborough Formation on the southeast side of the fault dips steeply to the southeast near the fault line. On the northwest (hanging-wall) side of the fault, the Gautreau Formation, basal Weldon Formation, and Boyd Creek Tuff all dip steeply to the northwest and are cut off by the fault east of Salem. Well 326 just southwest of Hillsborough was spudded on the hanging wall and intersected the fault zone at a vertical depth of 518 m. The well is located 340 m northwest of the fault trace, indicating that the Saint-Joseph Fault dips at 55° to 60°NW in that location.

On the east side of Petitcodiac River at the shoreline section near Belliveau Village, the Gautreau Formation on the northwest side of the break is faulted over the Weldon Formation on the south side (for more details, see Park and St. Peter 2005, their Fig. 17, 18). Grey mudstone and siltstone of the Gautreau Formation form a mass of breccia with recognizable shear surfaces and minor folds. The brecciation and attendant tectonic features are attributed to rising of the Gautreau Formation — including its subsurface rock salt — into the near-surface freshwater zone with the consequent dissolution and collapse of the overlying mudrocks (Park and St. Peter 2005).

Farther northeast along LeBlanc Creek and near Saint-Joseph, the location of the fault is indicated by a dip reversal in beds of the Albert Formation on either side of the fault (Plate 4). Two phases of tectonic folding appear in oil shales of the Albert Formation at LeBlanc Creek (Park and St. Peter 2005). Kinematic indicators from an F_1 bedding-parallel deformation show a movement of top-to-the-south or southwest. The outcrop-scale structural analysis at LeBlanc Creek agrees with the map-scale evidence that the Saint-Joseph Fault is a northwest-dipping dislocation with a substantial reverse displacement.

The history of movement on the Saint-Joseph Fault prior to the reverse displacement that offsets the Hillsborough Formation is unclear. Presumably it, like the Caledonia Fault, played an active role in consecutively inverting the Horton and Sussex groups against the buttress of the Caledonia basement. The displacement affecting the Hillsborough Formation was probably trivial in comparison with the total offset on the fault (Fig. 14). The limited information available at the outcrop level suggests that the Saint-Joseph Fault does not displace the unconformity at the base of the Mabou Group (Hopewell Cape Formation) between Petitcodiac River and Saint-Joseph (Plate 4). The covering strata of the Hopewell Cape Formation preclude finding evidence of the Saint-Joseph Fault continuing to the east of or being offset by the Memramcook East Fault (Fig. 84; Plate 3). Until such contrary evidence is demonstrated, the contact between the Westmorland Uplift and Moncton Subbasin east of the Memramcook East Fault is interpreted as an unbroken unconformity (Fig. 6, 84).

A syncline with a northeast-trending axis approximately parallel to the trace of the Saint-Joseph Fault is located on the footwall side of the fault on the east side of Petitcodiac River. The synclinal fold is well exposed in the riverside section near Belliveau Village (Park and St. Peter 2005, their Fig. 17). The syncline, which is cored by the Weldon Formation, presumably formed in conjunction with the late compressional event reflected by the reverse displacement on the Saint-Joseph Fault. Similarly, bedding attitudes from isolated outcrops suggest the presence of a footwall syncline on the south side of the Saint-Joseph Fault between Peck Creek and Frederick Brook (Plate 4). That east-northeast-plunging fold, although broken by minor northeast-striking faults, warps the Round Hill, Gautreau, Weldon, and Hillsborough formations.

Salem Fault

The Salem Fault (Fig. 84) is a northeast-trending splay of the Saint-Joseph Fault. It can be located by a dip reversal in bedding from Isaiah Corner in the southwest to Weldon in the northeast where it is concealed by the overlying Hopewell Cape Formation (Plate 4). Fractures associated with the fault are exposed in outcrops of red mudstone of the Weldon Formation along Bull Creek on the west side of Highway 910. Both a northeast- and a northwest-trending group of fractures have been noted. The northeast group comprises two dominant sets: one set strikes at about 15° to 20°, and the second set strikes at about 40° to 50°. Both sets dip steeply, and their intersection breaks the mudstone into a diamond-shaped pattern in plan view. In other places, the northwest group of fractures dominate. Those fractures, as with the ones in the northeast group, are steeply dipping, anastomosing, and show two dominant trends at about 110° to 115° and 150° to 155°.

The Salem Fault, like the Saint-Joseph Fault, is interpreted as an up-on-the-northwest reverse structure, suggesting that the fold on the southeast side of the fault (evident from Weldon to

Salem) is a footwall syncline. The Salem Fault is interpreted for two reasons to lie between Wells 247 and 251. The wells are located in the Weldon area and lie west and east, respectively, of the interpreted fault trace (Plate 4). First, the Boyd Creek Tuff (a reliable marker) lies at depth interval 54.9 m to 72.6 m in Well 247 but is absent in Well 366, which lies 450 m to the northeast. Such a relationship demands either that the tuff dips to the west and subcrops west of Well 366 or that a fault exists between the two wells with a downthrow to the west. Second, the Boyd Creek Tuff in Well 251 is at depth interval 254.3 m to 263.7 m; in Well 247 it is at 54.9 m to 72.6 m. The geometry suggests that the Salem Fault passes between Wells 247 and 251 and that the northwest side of the fault has moved up relative to the southeast side.

The location of the Salem Fault on the east side of Petitcodiac River is unknown (Plate 4). The Boyd Creek Tuff is absent in Well 320 but present in adjacent Wells 226 and 229. It is not known if the absence of the tuff in Well 320 is related to movement on the Salem Fault or to halotectonics and erosion associated with the rock salt in the underlying Gautreau Formation.

Cuttings from Well 290 located 1.5 km southwest of Isaiah Corner offer circumstantial evidence that the Salem Fault is a northwest-dipping reverse dislocation. In that well, grey mudstones and siltstones of the Gautreau Formation, exposed at surface near the well, pass downward into red mudstone and siltstone, the latter at a depth of 244 m to 645 m. The red section presumably represents the Weldon Formation, for it sits on red and grey conglomerates and grits of the Round Hill Formation, the latter occupying the section from 645 m to end-of-hole at 1033 m. If the well stratigraphy has been interpreted correctly, the Gautreau Formation must structurally overlie the younger Weldon Formation on the hanging-wall side of the Salem and Saint-Joseph faults.

The presence of the Round Hill Formation below a depth of 645 m in Well 290 and exhumed Round Hill immediately south of that well on the southeast side of the Saint-Joseph Fault seems to refute the interpretation that either the Salem or Saint-Joseph faults are northwest-dipping reverse structures. A possible explanation for this apparent ambiguity is proposed later under ***Compressional Faults and Folds***.

The *Weldon Syncline*, on the basis of field relationships, well records, and seismic reflection profiles (Plate 4), can be mapped at surface and in the subsurface from Berryton eastward to Gautreau Village (see St. Peter 1992, his Plate 92-35). The syncline, like other folds on the northwest side of the Saint-Joseph Fault, was in all probability formed at the same time as that fault and its subsidiary Salem Fault. The Weldon Formation and older units of the Sussex and Horton groups are more tightly warped than the unconformably overlying Hillsborough Formation (Fig. 14), demonstrating that most displacement on the faults predated Windsor deposition.

Edgetts Landing Fault

The Edgetts Landing Fault, as presently understood, is a subsidiary of the more important Dorchester and Caledonia faults (Fig. 14; Plate 4). It is mapped from the headwaters of Frederick Brook, where it merges with the Dorchester Fault (McLeod 1980), to Petitcodiac River at Edgetts Landing (Fig. 84), where it was first identified by Wright (1922, his Map 68A).

Its continuation east of Petitcodiac River is unclear, but it may swing north and define the broken boundary between the Round Hill and Albert formations at the south end of the riverside section at Boudreau Village (Park and St. Peter 2005, their Fig. 11). The location of the fault on the west side of Petitcodiac River is shown by offsets of the Albert, Round Hill, Weldon, Hillsborough, Macumber, Upperton, Hopewell Cape, and Boss Point formations. In the Albert Formation at Frederick Brook, the Edgetts Landing Fault with its associated fracture zone is believed to be the main structure that provided the migration pathway for emplacement of the bitumen that formed the historically famous albertite vein (Wright 1922; Alcock 1948a; King 1963; St. Peter 1987; Park and St. Peter 2005).

The disposition and movement history on the Edgetts Landing Fault have been assessed by Park and St. Peter (2005, p. 89). In the Albert Formation at Frederick Brook, the fault displaces early (prefault) F_1 and F_2 folds. Near its trace, the fault drags bedding into subparallel disposition with the northeast-striking and steeply dipping structure. On the south side of the gypsum quarries west of Edgetts Landing, the fault shows a downthrow of 60 m to 75 m on the Windsor Group and a later, opposite downthrow of 30 m to 50 m on the Hopewell Cape and Boss Point formations.

Dorchester Fault

The surface trace of the Dorchester Fault (Fig. 84; Plates 4, 5) is approximately located as mapped by Gussow (1953, his Fig. 5). The trace can be followed from Peck Creek in the west, where it was first observed by Norman (1941a), to just north of Woodhurst in the east, a distance of 25 km (Fig. 84). Although it obviously cuts strata of the Boss Point Formation near Albert Mines and is marked by a lineament in the Boss Point Formation east of Boudreau Village, it is difficult to prove displacement in beds younger than the Cole Point Member of the Boss Point Formation east of Highway 2.

At Peck Creek, Gussow (1953) and McLeod (1980) report that steeply dipping conglomerate beds of the Hillsborough Formation face the Caledonia basement to the north, implying that the basement has overridden the conglomerates. A north-over-south reverse displacement is also implied by the gradual increase in dip from north to south of the Albert beds along Frederick Brook (Fig. 14; Plate 4). A drag fold in the Albert has a slightly overturned limb at the fault trace against the Hopewell Cape Formation (St. Peter 1989b). Therefore, the reverse displacement, at least in part, is a late movement and postdates the Mabou Group. The map pattern at Albert Mines and east of Boudreau Village, where the Boss Point Formation is more completely eroded on the north side of the fault, suggests the late reverse displacement also offset the Cumberland Group.

Between Albert Mines and Petitcodiac River, an earlier and opposing sense of displacement can be tentatively demonstrated on the Dorchester Fault. For example, Windsor rocks exist on the north side of the fault at Edgetts Landing yet are absent in nearby Wells 698 and 708, just south of the fault. The relationship implies that the 'block' those two wells were drilled on was either topographically high during Windsor deposition or was elevated, and the Windsor eroded, before deposition of the Mabou Group (Hopewell Cape Formation). Regardless, the south side of the Dorchester Fault in that area appears to have been topographically higher than the north side during or following Windsor time. This implied offset of early north-side-down would agree or complement the more easily demonstrated movement of early north-side-down on the subparallel Wilson Brook Fault (see below).

Gussow (1953, his Fig. 11) provides four sections across the Dorchester Fault that he stated were based on three seismic reflection profiles. In all sections he displays the fault as a moderately northwest-dipping, compressional (reverse-thrust) break. Accordingly, he shows the western end of the fault carrying a thick 'Carboniferous' succession in the Moncton Subbasin against and over the Caledonia Uplift, and the eastern end of the fault carrying the Westmorland Uplift with its thin Carboniferous cover over the thicker Carboniferous succession in the Sackville Subbasin. In stark contrast, Martel (1987) shows two cross-sections across the Dorchester Fault along the north side of the Sackville Subbasin. On the basis of seismic profiles shot by Chevron Standard Ltd. in 1981 (lines 29, 49, 37Y, and 41Y), he interprets the Dorchester Fault as a down-to-the-south extensional normal structure. Gussow's W−X section and Martel's B–B' section lie along nearly the same north–south line.

The present authors have not attempted to resolve the discrepancy in interpretation between Gussow and Martel. However, an outcrop about 1 km north of Woodhurst on the west side of a dirt road beside Breau Creek seems to 'favour' Gussow's interpretation. Coincidentally, the outcrop lies very near both Gussow's W−X section and Martel's B–B' section. The outcrop shows a fault between reddish brown pebble to cobble conglomerate and friable green micaceous sandstone. The conglomerate and sandstone are considered to be Hopewell Cape lithotypes. The fault is not likely the Dorchester Fault but must lie close to the main fault trace. It has a strike of 40° and a dip of 80°NW. Tellingly, shears in the conglomerate adjacent to the fault plane have an average strike of 80° and a dip of 55°N. Those shears, if they reflect the regional attitude of the Dorchester Fault, imply that the fault dips to the north.

The more easterly part of the Dorchester Fault lying east of Upper Dorchester is discussed later under ***Sackville Subbasin Structure***.

Wilson Brook Fault

The Wilson Brook Fault (Fig. 84) is identifiable by minor offsets on formations in the Wilson Brook area (Plate 4). For instance, the Hillsborough Formation lies on basement on the north side of the fault, yet the Gays River lies on basement on the south (high) side of the break. The fault seems to show minor late movement, as it cuts off the northwest-striking Hopewell Cape Formation along the main branch of Wilson Brook. However, the major displacement on the Wilson Brook Fault predates Windsor deposition. This is interpreted from Chevron–Irving seismic reflection line 65YA, which was shot in 1984 in a north-northwesterly direction from near the headwaters of the small streams about 1.5 km northeast of the community of Demoiselle Creek to near the mouth of Weldon Creek. Well 698 just southwest of Edgetts Landing was drilled later (in 1998) on that line. Despite the Albert Formation being absent at surface along the basement contact between the Dorchester and Wilson Brook faults in the headwaters area of Wilson Brook, an incredible 900 m of Albert strata were intersected in Well 698. The base of the Albert had still not been reached by the end-of-hole at 1375 m. Nearby Well 708 cut Albert rocks from 250 m to 2050 m and terminated at that depth while still in the formation, further emphasizing the thickness of the Albert Formation in this area.

An interpretation of seismic line 65YA reveals a major fault — the Wilson Brook Fault — south of Wells 698 and 708. The fault dips steeply to the north and has an apparent downthrow to the north on the basement contact of about 1.5 km to 2.0 km, dependent on seismic velocity. On the basis of a broad open anticline (rollover fold) being apparent in reflectors on the north side of the fault, the Wilson Brook Fault is interpreted as a syn-Horton growth fault. It is thus concluded that the Wilson Brook Fault represents the southeastern depositional margin of the eastern part of the Moncton Subbasin in Horton and probably Sussex time. The conclusion is supported by evidence that the Caledonia basement block remains high on the south side of the fault east of Petitcodiac River as far as the Harvey–Hopewell Fault. For example, in Well 706, the basement lies at a depth of 1043 m, and the Horton and Sussex groups have a combined thickness of less than 300 m.

Northwest- to North-Trending Faults

Northwest- to north-trending faults (Fig. 84) in the Moncton Subbasin are far less obvious than the major northeast-trending breaks, the latter of which have played the lead role in controlling the resultant, present-day structural geometry. Nevertheless, northwest-trending faults have had sufficient influence on sedimentation and subsequent offset or inversion of the succession to warrant brief mention. They can be grouped into those with normal or transcurrent displacement and those with compressional movement. Because most of the northwest faults are generally considered to be of subordinate importance, few have been assigned names.

Extensional and Transtensional Faults: The following areas have northwest extensional or transcurrent faults with notable displacement: Prosser Brook, Upham Brook, Caledonia Mountain, Frederick Brook (west), Frederick Brook (east), Demoiselle Creek, La Montagne, and Memramcook East. Almost all of these faults are shown on Figure 84 as well as on their respective map plates.

The northwest-trending fault at *Prosser Brook* defines the basement boundary west of the brook. Park et al. (2007) describe the structure as a sidewall ramp, an active tear fault supporting or complementing displacement on the south-vergent compressional Caledonia Fault. Right-lateral displacement is implied by rotation of bedding in the Hillsborough Formation near the fault line (Plate 4). Substantial downthrow to the east is shown by the Albert and Hillsborough formations both striking regionally southwest into the Caledonia basement, which is exhumed on the west side of the break.

At *Upham Brook*, two northwest-trending cross faults break the formations on the north side of the Caledonia Fault. They define the east and west boundaries of a block of Round Hill Formation faulted down against the Albert Formation (Plate 4). The more westerly of the two cross faults is the larger break. Close outcrop control demonstrates that the break causes an apparent right-lateral offset of about 400 m on the basement, the Caledonia Fault, and on the unconformity at the base of the Hillsborough Formation. Further evidence of the western fault is provided by rocks interpreted as Round Hill Formation on the east side dipping and younging toward the west, and by the Albert rocks on the west side dipping to the southeast toward the basement and cross fault. The rocks between the cross faults are assigned only tentatively to the Round Hill Formation. The grey conglomerates and grits in that unit have no observable interbeds of organic shales or micaceous ripple-laminated sandstones, two lithotypes that characterize the adjacent Albert Formation. If the formational assignment is correct, it would demand a substantial downthrow on the eastern side of the western cross fault.

At *Caledonia Mountain* on the north side of the Caledonia Fault, a northwest-striking cross fault marks the boundary between the Albert Formation on the west and the Round Hill Formation on the east. Beds of Albert shale are dragged clockwise, assuming a north–south strike and a subvertical dip within metres of the fault trace (St. Peter 1989a). The drag fold indicates a right-lateral component of movement on the northwest-trending fault. The younger Round Hill Formation on the east side of the fault suggests a substantial downthrow to the east. The interpreted east-side downthrow is further indicated by a comparison of the sections cut in Wells 353 and 266. In Well 353 just north of Rosevale, 294 m of conglomerates of the Hillsborough Formation rests on the Albert Formation; in Well 266 at Baltimore, 657 m of Hillsborough strata lies on 448 m of Weldon mudstones. The Albert was not reached in Well 266, which was discontinued at 1118 m depth. The huge thickness of Weldon Formation on the east side of the fault demonstrates that a substantial part of the fault movement predates the unconformably overstepping Hillsborough Formation.

West of Frederick Brook, the Albert Formation is in contact with crystalline basement and the Round Hill Formation along a northwest-trending fault (Plate 4). The tectonics on that faulted boundary are not well understood but are undoubtedly complex. Canadian Occidental Petroleum Ltd. put down several boreholes in the Albert Formation east of the fault along Frederick Brook (Macauley and Ball 1982; St. Peter 1988). Those boreholes and outcrops just east of the fault line indicate that the Albert Formation contains progressively more conglomerate and sandstone from east to west as the fault is approached. The fault thus appears to have existed, had a substantial escarpment, and was involved in the depositional history of the Albert Formation.

The Albert beds immediately east of and along the south part of the fault dip west and face the Caledonia basement, whereas those along the north part of the fault dip vertically and face away from the basement (Plate 4). This could be interpreted as resulting from an east-striking splay of the Edgetts Landing Fault lying between the west- and east-facing panels (see St. Peter 1988, his Plate 87-62). Alternatively, the west- and east-facing panels may be on separate fault-bounded tectonic slices that were juxtaposed against the Caledonia basement block during inversion of the Albert Formation. The inversion may have resulted from east–west orthogonal compression that reverse-faulted the Albert over the Caledonia basement or, conversely, the basement over the Albert. Evidence of an east–west-directed stress field in this area is discussed below under ***Compressional Faults and Folds***. Another possibility is that a significant lateral tear component of movement developed on the northwest-trending fault in sympathy with the north-over-south vergence on the Caledonia Fault and/or Dorchester Fault.

Two northwest-trending faults lie *east of Frederick Brook* on the north side of the Edgetts Landing Fault. The more westerly fault drops the Round Hill Formation on the east down against the Albert Formation on the west. The more easterly one faults the Hillsborough Formation on the east down against the Weldon Formation on the west. The Albert Formation strikes toward the northwest and dips vertically within a few metres of the trace of the west fault (St. Peter 1988, his Plate 87-62), whereas the Hillsborough Formation dips anomalously at 60°E on the hanging-wall side of the east fault. The down-to-the-east displacement on the two faults is substantiated by a comparison of surface exposures with the intersection of the faults in adjacent Wells 350 and 695. The fault between the Albert and Round Hill formations that appears at surface is present at a depth of 278 m in Well 350, yielding a dip for the fault of about 50°E. Well 695 cuts only one fault, which at a depth of 489 m marks the boundary between the Round Hill Formation and underlying Albert Formation. Two possibilities could explain why the two faults were not intersected in Well 695: either the west fault is cut by the east fault or the east fault is cut by the west fault, west of the well's spud location. Depending on which fault model is correct, the east fault has an indicated dip of 60° to 80°E.

The *Demoiselle Creek Fault* was named by McLeod (1997) for a northwest-trending fracture system cutting the Hopewell Cape and Boss Point formations between Curryville and Livingstones Hill (Plate 4). The fault was discovered as the result of diamond drilling and trenching for copper-, lead-, and zinc-bearing sulphides by Noranda Exploration Company Ltd. in 1992 and 1993 (McLeod 1997). Although the main fault shows only a few tens of metres of normal downthrow to the east on the Hopewell Cape–Boss Point boundary, it and subparallel splays provided the fracture pathway for base-metal-bearing fluids to mineralize the basal grey sandstones of the Boss Point Formation (McLeod 1997). This mineralization is described in Chapter 4.

The Demoiselle Creek Fault may be a late reactivation of a more fundamental fault in the underlying Horton and Sussex groups. For example, the Albert Formation section in Well 698 just southwest of Edgetts Landing is greater than 900 m thick yet is absent along the basement contact west of Demoiselle Creek. Somewhere between the basement and Well 698, substantial down-to-the-east relief is required to account for the Albert section in Well 698. Syn- or post-Albert northwest-trending normal faults could be present below the mineralized fracture zone at Demoiselle Creek.

La Montagne Fault is exposed on an unnamed brook about 1 km northeast of the community of La Montagne (Plate 4). The fault was first noted there by Norman (1941a), and its extension farther to the east was mapped by Gussow (1953, his Fig. 5). Gussow showed it as a north-dipping reverse fault on his map but provided no text to explain his interpretation. St. Peter (1989b) named the fault and later (1992) gave a brief description. Small outcrops of the Albert Formation and McQuade Brook Formation, respectively, on the south and north sides of the fault trace provide no conclusive evidence of the dip or sense of offset on the fault. Grey kerogenous shale, micaceous sandstone, and lithographic limestone beds of the Albert Formation are contorted and in part dip vertically. They are pervaded by calcite veins. Greyish green siltstone of the McQuade Brook Formation on the north side of the fault ranges from fractured to brecciated and is cut by numerous calcite veins. The McQuade Brook Formation is faulted against the Albert Formation, suggesting minor loss or duplication of section along La Montagne Fault. Accordingly, the fault likely has minimal dip-slip displacement.

The *Memramcook East Fault* is a northwest-trending break located near Memramcook East (Plate 3). It has been known for over 125 years through earlier reports by Ells (1883) and Bailey (1898) of base metals and fluorite veins in the area. Norman (1941b) and Gussow (1953) noted the fault but neither provided a description. The fault was named by McLeod and Ruitenberg (1978, their Plate 78-25A), who provided a brief description of the quartz–barite veins and associated lead–copper mineralization. The surface location and a westerly dip on the fault plane at Memramcook East were ascertained by trenches and drillholes at the barite occurrence (Hamilton 1968; St. Peter 1992). St. Peter (1992) estimated downthrow-to-the-west on the basement rocks beneath the Memramcook Formation at 700 m on the basis of seismic reflection lines that cross the fault. Popper (1965, his Plate 3) mapped an anticline with a southeast-trending axis in the Memramcook Formation between the Memramcook East Fault and the basement inlier at Prairie Brook (Plate 3). The inlier and the steeply dipping, east-facing beds of Memramcook Formation from the mouth of Prairie Brook to Memramcook East suggest that the Memramcook Formation was inverted against a block of Westmorland Uplift (basement), now shallowly buried below the Boss Point Formation east of Prairie Brook. Basement granite was intersected at a depth of 149.4 m in Well 401, which lies 10.7 km northeast of the exhumed basement at Prairie Brook (Plate 2). The Memramcook East Fault therefore in part defines the inversion zone along the eastern boundary of the Moncton Subbasin and locally marks the eastern boundary of the Moncton Subbasin with the Westmorland Uplift.

Compressional Faults and Folds: In the Moncton Subbasin, faults with a northwesterly or northerly strike and reverse or thrust displacement appear to be restricted to the southeastern part of the subbasin. The obvious faults of this type occur on the west side of Petitcodiac River in the structural panel between the Saint-Joseph and Edgetts Landing faults (Fig. 84; Plate 4). Two unique aspects of the structure in this area are 1) the anomalous southeast strike and northeast dip of Sussex units between Round Hill and Frederick Brook, and 2) the associated anomalous northerly orientation of the fold in the Windsor Group at Gray Brook. The major structure in this panel is a northwest-striking and northeast-dipping, reverse-thrust fault on the west side of Round Hill (Plate 4; also see St. Peter 1989b, his Plate 89-104B). The surface trace of that fault is marked by two outcrops on a small tributary of Weldon Creek. One outcrop, on the hanging wall, is red pebbly sandstone of the Round Hill Formation. Beds in it strike 155° and dip vertically. The other outcrop, on the footwall, is red mudstone of the Weldon Formation and is cut by two pervasive shear fabrics. The early shears strike 50° and dip 35°NW; the late shears are at 130° and dip 55°NE. The early shears apparently reflect displacement on the Saint-Joseph–Caledonia fault system. The late shears are considered to be approximately parallel to the northwest-trending reverse fault that carries the Round Hill Formation in the hanging-wall block.

Rocks in the hanging wall of the northwest-trending fault are a repetition of the Round Hill and Weldon formations that occur in the footwall. However, the hanging-wall panel is rotated clockwise by about 40° relative to the footwall panel. Also, a poorly defined southeast-plunging anticline in the hanging wall is cored by massive conglomerate that forms Round Hill. The anticline is cut by minor northeast-trending faults, two of which occur in the bed of Peck Creek east of Round Hill (Park and St. Peter 2005, their Fig. 22). In addition, northwest-striking and northeast-dipping reverse faults cut the Sussex Group at Peck Creek (see Park and St. Peter 2005, their Fig. 22). Those faults are subparallel to bedding and have repeated or partly repeated the Round Hill Formation. They are responsible for an exaggerated impression of the formation's thickness between Round Hill and Frederick Brook (Plate 4).

As noted earlier under ***Salem Fault***, the presence of the Round Hill Formation below a depth of 645 m in Well 290 and of exhumed Round Hill Formation immediately south of that well on the southeast side of the Saint-Joseph Fault seems to refute the interpretation that either the Salem or Saint-Joseph faults are northwest-dipping reverse structures. The outcrop of Round Hill Formation at Round Hill, together with its structurally higher position there relative to its stratigraphic position in Well 290, is concluded to result from reverse displacement on the northwest-trending reverse fault on the west side of Round Hill. To produce this geometric configuration, the Saint-Joseph Fault must have acted as a right-lateral tear fault during the west-vergent displacement on the northwest-trending reverse fault.

The anomalously oriented stress field reflected by the northwest-striking reverse faults cutting the Sussex Group near Round Hill continued its influence from Tournaisian into Westphalian time. For example, rocks from the Windsor age (Hillsborough Formation) to the Cumberland age (Boss Point Formation) that lie off the northeast nose of the exhumed Caledonia Uplift as far east as the Harvey–Hopewell Fault exhibit anomalous, discordant north-trending folds. The two most obvious folds are the syncline in the Windsor Group at Gray Brook and the north-trending syncline in the Boss Point Formation north of Beaumont (Plate 4). The regional fold and fault geometry in this area suggests that the 'Carboniferous' succession was compressed and wrapped around the hard northeast nose of the Caledonia crystalline basement, which acted as a buttress. In keeping with this scenario, the syncline at Wilson Brook in the Windsor Group appears to have an east-trending axis and an easterly plunge beneath the unconformably overlying Hopewell Cape and Boss Point formations. However, the absence of any Windsor rocks at Well 698 near Edgetts Landing suggests either that the fold is cut by a buried northwest-trending fault with a western downthrow or that the fold is doubly plunging. A doubly plunging fold with a northerly striking minor axis would be consistent with the regional tectonics of this area. In fact, the syncline at Gray Brook may have been doubly plunging before its southern part was severed by the Edgetts Landing and Dorchester faults.

Summary, Eastern Moncton Subbasin Structure

Tectonism in the eastern Moncton Subbasin was most recently analyzed and discussed by Park and St. Peter (2005) and Park et al. (2007). They conclude that the tectonic setting of the Horton and Sussex groups in the southeastern margin area of the subbasin from Prosser Mountain Fault in the west to Memramcook in the east is characterized by a fold–thrust belt. The end-Horton and end-Sussex inversion events in the fold–thrust belt were accomplished by northwest-dipping reverse or thrust faults assisted by northwest-striking sidewall ramps or tear faults. They also conclude that the structural style west of the Prosser Mountain Fault is different and reflects an inversion of the Horton and Sussex groups via oblique dextral transpression (St. Peter 1992, 1993).

The current report offers nothing to substantially refute the conclusions of Park and St. Peter (2005) and Park et al. (2007) but does provide the following additional structural details.

- Northeast-striking faults such as Gordon Falls (where it occurs just west of the report area), Gowland Mountain, Prosser Mountain, Caledonia, Gaytons, and Wilson Brook are deemed to be basement–basin-bounding structures. Coarse-grained lithofacies in the Horton and Sussex groups along those faults suggest their early extensional or transtensional history.

- Northwest-striking cross faults such as those at Prosser Brook, Caledonia Mountain, Frederick Brook (west), Memramcook East, and perhaps Demoiselle Creek (a concealed fault) were likely active, and, together with the more dominant northeast-striking faults, they assisted in developing accommodation space during the Horton, Sussex and even Windsor group allocycles.

- The style and orientation of faults and folds around the northeastern nose of the exhumed Caledonia Uplift are an aberration of the normal northeasterly trend. The north trend of folds and the north-to-northwest strike of reverse faults there likely resulted from the succession having been wrapped around the hard Caledonia basement block.

CUMBERLAND SUBBASIN STRUCTURE

The Cumberland Subbasin is a late Paleozoic east–west trending depocentre and part of the larger composite Maritimes Basin (Fig. 6, 7). It contains up to 7 km of mainly terrestrial fill and one marine sequence, the Windsor Group (Ryan and Boehner 1994). The southern border of the Cumberland Subbasin occurs in Nova Scotia and is defined by the Cobequid Highlands. The northwestern boundary of the subbasin with the Caledonia Uplift in New Brunswick is defined by the Harvey–Hopewell Fault (Fig. 84). The northern boundary is delimited by the northern splay of the Shepody–Beckwith Fault, which tracks along the southern margin of the Hastings Uplift, a buried crystalline basement block (Fig. 84). Thus, the definition of the Cumberland Subbasin proposed herein differs somewhat from that of Ryan and Boehner (1994), who include the structurally separate Sackville Subbasin within their Cumberland Subbasin.

The Cumberland Subbasin in New Brunswick features three significant intrabasinal structures: the Dennis Beach Fault and Lockhart Lake Fault on the west side of Chignecto and Shepody bays (Plate 6), and the Maringouin Anticline on the east side of Shepody Bay (Plates 4–6).

Harvey–Hopewell Fault

The northwestern boundary of the Cumberland Subbasin with the Caledonia Uplift in New Brunswick is defined by the Harvey–Hopewell Fault (Fig. 84; Plates 4, 6). It is a northeast-trending major break that juxtaposes mainly Mabou Group (Hopewell Cape Formation) on the southeast against the Cumberland Group (Boss Point Formation) on the northwest. It can be tracked from Point Wolfe on the Bay of Fundy northeastward to Hamilton Creek, where it is offset by the northern splay of the Shepody–Beckwith Fault. It continues to the northeast where it defines the western limit of the Sackville Subbasin. The fault was first mapped by Flaherty and Norman (1941) and Norman (1941a) and was subsequently named by Gussow (1953).

Before demonstrating that the Harvey–Hopewell Fault and its subparallel companions (the Dennis Beach and Lockhart Lake faults) are essentially Late Carboniferous compressional reverse-thrust structures, the authors will discuss the probable nature of the ancestral fault along which the present Harvey–Hopewell Fault developed. The contact between the Hopewell Cape Formation and underlying basement is exposed at Dickson Brook, about 1.5 km north of Herring Cove. The basement exhibits a system of northeast-trending fractures. Each fracture steps down to the southeast, allowing an incrementally thicker section of Hopewell Cape sediment to accumulate on their downthrown side. It is thus believed that, somewhere between Dickson Brook and Herring Cove and buried beneath the unconformably overlying Boss Point Formation, a major down-to-the-southeast dislocation marks the location of the ancestral extensional Harvey–Hopewell Fault and depositional margin of the Cumberland Subbasin. The thickness of the Hopewell Cape Formation differs markedly across this region: between Dickson Brook and Demoiselle Creek it rests as a condensed section on the Caledonia basement, but on the southeast side of the present compressional Harvey–Hopewell Fault it appears as hundreds of metres of section. This immense range in thickness demonstrates that the precursor extensional fault either lies along the present fault line or is buried just northwest of it below the Boss Point Formation. The existence of that fault is further suggested by the thick section of Hopewell Cape Formation at Herring Cove, which dips toward the Caledonia basement to the northwest.

Gussow (1953, p. 1772) cites two locations where the Harvey–Hopewell Fault is exposed. At Owls Head on the west side of Rocher Bay, the fault dips 35° to 60°SE and upthrusts massive conglomerate of the Hopewell Cape Formation over overturned beds of the Boss Point Formation (Plate 6; also see Webb 1963, his Fig. 4). Slickensides on the fault plane pitch at 90°, suggesting mainly dip-slip motion in the area. A syncline in the Boss Point Formation in the footwall block west of Owls Head is presumably related to the same compressional event that formed the fault. The fault is also exposed on the upper part of Chemical Creek, where chlorite schist overlies Hopewell Cape conglomerate along a plane dipping 50°SE.

At Herring Cove a 7 m wide concealed interval occurs between northwest-dipping beds of Hopewell Cape conglomerate and adjacent quartz-pebble conglomerate and quartzose arenite of the Chignecto Bay Member (Boss Point Formation). A splay of the Harvey–Hopewell Fault is interpreted to pass through the concealed interval, although little evidence of deformation exists. The trace of the splay is demonstrated southwest of Herring Cove by the gradual cutting out of the southeast limb of a footwall syncline in the Boss Point Formation by the overriding Hopewell Cape Formation (Plate 6).

A steep cliff of polymictic conglomerate of the Hopewell Cape Formation lies on the southeast side of Highway 114 about 1 km north of Germantown. The conglomerate is cut by two sets of shears. The earlier shears strike approximately 30°, dip 55°SE, and have slickensides pitching 45° to 60°SW. The later shears strike 15°, dip 45°SE, and show slickensides pitching 40°S. The shears are interpreted to be related to movement on the Harvey–Hopewell Fault, the trace of which lies just a few tens of metres northwest of the cliff outcrop. They indicate that the fault is a reverse structure with a sinistral component of movement. Small outcrops of Boss Point sandstone occur along a sideroad ditch about 300 m northwest of the cliff exposure of Hopewell Cape conglomerate. The sandstones dip to the southeast, demonstrating that the older Hopewell Cape beds override the Boss Point beds.

From Riverside–Albert northeast to Hamilton Creek, the degree of shortening on the Harvey–Hopewell Fault system is implied by the following: 1) a northeast-trending slice of basement volcanic rocks from the footwall block of the ancestral normal fault was upthrusted over southeast-dipping Boss Point Formation between Chemical Creek and Hamilton Creek, and 2) an out-of-sequence wedge of gypsum and anhydrite of the Lime-kiln Brook Formation was translated and smashed against the basement slice along Chemical Creek. Northwestern vergence on the fault system is demonstrated by a consistent southeast-dipping shear fabric in the basement mafic volcanic rocks at Hamilton Creek and by a footwall syncline in the Chignecto Bay Member (Boss Point Formation) at Sawmill Creek.

Webb (1963) estimates that at least 15 km of left-lateral displacement took place on the Harvey–Hopewell Fault, basing his argument on the offset of an alluvial fan in the Hopewell Cape Formation. The clast content in the Hopewell Cape Formation in the southwestern part of the fan is distinctly different from that in the northeastern part. Between Herring Cove and Riverside–Albert, the Hopewell conglomerate is dominated by clasts of schistose sandstone, arkose, chlorite schist, slate, and subordinate to minor volcanic and plutonic rocks. Yet at Shepody Mountain and Hopewell Cape, the conglomerate is dominated by granite, granodiorite, mafic and felsic volcanic rocks, and subordinate to minor metasedimentary clasts. The contrast in clasts between the southwestern and northeastern conglomerates is explicable by comparing the dominant rock types in the Caledonia Uplift northwest of those two areas (see McLeod et al. 1994). The Caledonia Uplift northwest of Alma and Germantown contains abundant metasedimentary and minor plutonic rocks, whereas the major rock bodies northwest of Shepody Mountain and Hopewell Cape are plutonic and volcanic suites with subordinate metasedimentary rocks. A comparison of Hopewell Cape clasts from these two areas with their adjacent Caledonia bedrock demonstrates that the formation in both areas was not laterally translated from its deposition site to any great extent.

Dennis Beach Fault

A fault at the west end of Dennis Beach at Rocher Bay was noted by Flaherty and Norman (1941) and Gussow (1953) as a local contact between the Hopewell Cape Formation and Triassic Fundy Group redbeds. They provided no details on the fault or on its Late Carboniferous or post-Triassic movement. However, Webb (1963) clearly understood the fault's importance, giving a detailed description of its related deformation and associated Late Carboniferous left-lateral displacement. In fact, he interpreted it as more likely being the master fault in the area and recommended labelling it the Harvey–Hopewell Fault.

The Dennis Beach Fault (Fig. 84) in all probability underwent more displacement than did the Harvey–Hopewell Fault. The following points support this hypothesis. The pervasive shearing across a zone greater than 20 m wide at Dennis Beach is much more severe than along the Harvey–Hopewell Fault at Owls Head (Webb 1963). The basinward mudrocks of the Maringouin Formation are translated to the northwest, presumably for a considerable distance (kilometres?), where they are juxtaposed against the basin-edge (proximal) conglomerates of the Hopewell Cape Formation between Dennis Beach and Beaver Brook. Northeast of Beaver Brook for about 2 km along the fault trace, the western edge of the hanging-wall Maringouin Formation completely overrides the Hopewell Cape Formation and Harvey–Hopewell Fault and lies structurally above the Boss Point Formation. At Riverside–Albert, where the Hopewell Cape Formation and Harvey–Hopewell Fault once again reappear from under the leading edge of the Dennis Beach Fault, the upper part of the Lime-kiln Brook Formation is upthrusted over a lenticular wedge of Hopewell Cape conglomerate (Plates 4, 6).

The faulted boundary between the Lime-kiln Brook and Hopewell Cape formations at Riverside–Albert suggests that movement on the Dennis Beach Fault was facilitated by incompetent evaporites of the Windsor Group, interpreted to lie immediately below the

Maringouin Formation. Note that, at Riverside–Albert, the basal contact of the Maringouin Formation with Windsor limestone is apparently preserved, whereas farther southwest along the trace of the Dennis Beach Fault, gradually more of the basal part of the Maringouin is cut out. Webb (1963) refers to displacement on faults (inversion) in this part of the Cumberland Subbasin being accomplished by a regional décollement in the Windsor evaporites. The outcropping of selvages of late Windsor rocks above the sole of reverse-thrust faults at Riverside–Albert, Shepody Marsh, Chemical Creek, Lockhart Lake, Upper Dorchester, and Grande Anse (Plates 4–6) lends substantial credibility to his model. The anomalously steep dips in the Mabou and Cumberland groups on the northwestern and northern margins of the Cumberland Subbasin from Rocher Bay to Maringouin Peninsula (Fig. 84) also support Webb's thesis of salt kinematics facilitating basin inversion.

North of Riverside–Albert, it is not apparent where the regional displacement on the Dennis Beach Fault is transferred. It seems likely that a significant part of the displacement was passed to the branch of the Shepody–Beckwith Fault that crosses Shepody Bay toward Johnson Mills (Plate 4). The juxtaposition of Lime-kiln Brook sulphates at Hopewell Hill and Shepody Marsh against the severed nose of a syncline cored by Hopewell Cape conglomerate at Shepody implies a north-vergent structure, which accordingly has the requisite disposition to receive the apparent strain on the Dennis Beach Fault. The fault that lies less than 500 m southeast of the trace of the Harvey–Hopewell Fault from Chemical Road to Hamilton Creek is probably not the northeastern extension of the Dennis Beach Fault. The presence of younger Hopewell Cape Formation on the southeast side of the fault suggests it is a late extensional structure with downthrow to the southeast.

Lockhart Lake Fault (and Maringouin Anticline–Hard Ledges Syncline)

Northeast-trending faults on the west side of Lockhart Lake and near the copper deposit at Upper New Horton were noted by Flaherty and Norman (1941). Gussow (1953, his Fig. 5) refined the location and named the structure the 'Lockhart Lake Fault.' He recognized that the major break occurs on the east side of Lockhart Lake, where it defines the lower structural boundary of the Maringouin Formation from Rocher Bay northeast to Upper New Horton.

The surface traces of the Lockhart Lake Fault and of the associated northeast-striking faults west of it are not exposed. However, steep to overturned bedding and the lenticularity of tectonic wedges of the Shepody, Enragé, and Boss Point formations indicate the fault locations as well as the complexity of faulting in the footwall of the Lockhart Lake Fault (Fig. 84; Plate 6). The footwall is characterized by what was probably a northeast-trending syncline in the Boss Point Formation, one that Gussow (1953) labelled the 'Long Marsh Syncline.' The hinge zone of the syncline is broken by a series of northeast-trending faults that created several small, juxtaposed structural panels. The panels are characterized by beds with dips and facing directions that are consistent within each panel but that oppose those of adjacent panels.

The magnitude of displacement on the main Lockhart Lake Fault is demonstrated by 1) the translation of gypsum and limestone of the Windsor Group (Lime-kiln Brook Formation) over the uppermost beds of the Shepody Formation east of Lockhart Lake, and 2) the Maringouin and Shepody formations being completely cut out on the hanging wall at Upper New Horton. Hundreds and likely thousands of metres of dip-slip offset are implied.

The location of the Lockhart Lake Fault in Shepody Bay is not known. It may track northeasterly and merge with the Shepody–Beckwith Fault west of Johnson Mills (Fig. 84; Plate 4). The northern vergence of both faults makes this interpretation plausible. Conversely, the fault may swing more easterly and define the northern, unexposed contact between the Lime-kiln Brook and Maringouin formations on Maringouin Peninsula at Pecks Cove (Plates 4–6). If the second interpretation is true, then the Maringouin Anticline (Fig. 71, section A–A'; also see Gussow 1953) at Pecks Cove is not a conventional anticline but instead is the broken roof zone of a salt-cored structure and yet another example of the décollement surface in the Windsor evaporites (see Webb 1963). (See ***Dennis Beach Fault***, above, for additional comments.)

Structural complexities that suggest such a setting occur in outcrops of the Lime-kiln Brook Formation on the eastern shore of Shepody Bay (Plate 6; Hamilton and Barnett 1970). (The gypsum, limestone, and red clastics were described in Chapter 2 under map unit **CLK$_g$**, ***Lime-kiln Brook Formation***.) The existence of a major south-dipping fault in this area is supported by the sections of Maringouin and Shepody formations north of the Lime-kiln Brook Formation on Maringouin Peninsula, which are cut by numerous south-dipping, low-angle, dip-slip minor reverse faults. Ryan and Boehner (1994) and Howie (1986) also map a major south-dipping, unnamed fault along strike from Pecks Cove on the north side of the Minudie Anticline in Nova Scotia. Under this model, the Hard Ledges Syncline, which lies farther north (Fig. 71, 72, 84; Plates 4, 5), is a footwall syncline to the Lockhart Lake Fault, thus being analogous to Gussow's Long Marsh Syncline at Lockhart Lake. The Lockhart Lake Fault is not depicted as the defining boundary between the north side of the Lime-kiln Brook Formation and the Maringouin Formation on Maringouin Peninsula, because the symmetry of the Maringouin Anticline is still preserved. (See ***Shepody–Beckwith Fault***, below, for more on the Hard Ledges Syncline.)

Shepody–Beckwith Fault

The Beckwith Fault in Nova Scotia is mapped in the northern part of the Cumberland Subbasin from Fox Harbour westward to the Minudie area, a distance of about 75 km (Howie 1986; Ryan and Boehner 1994). In a regional sense, the Beckwith Fault dips to the south, is located along the southern border of the Hastings Uplift, and lies beneath the salt-cored Minudie Anticline of the Cumberland Subbasin. The fault cuts the Pictou Group (Balfron Formation) along the eastern part of its trace near Pugwash (Ryan and Boehner 1994, their Map 90-13) yet is apparently overstepped by the Balfron Formation along the western part of its trace (Ryan and Boehner 1994, Map 90-12). Howie's interpretation (1986, his cross-sections A–A' and B–B') differs from that of Ryan and Boehner and shows the fault offsetting the Pictou Group along the western part of its trace as well.

Near Johnson Mills on the west shore of Maringouin Peninsula in New Brunswick (Plate 4), the lowest exposed beds in the type section of the Grande Anse Formation (Fig. 66, 67) are faulted against the Boss Point Formation along a major dislocation. The dislocation is interpreted to reflect the surface location of the buried southern margin of the Hastings Uplift, a shallow to deeply buried basement high separating the Sackville and Cumberland subbasins (Fig. 6). Outcrops in the intertidal zone and coastal cliffs south of Johnson Mills (Fig. 72) reveal a 90 m wide shear zone that cuts across the stratigraphy (see Browne 1991). The fault is interpreted as the westward extension of the Beckwith Fault of Nova Scotia (Ryan and Boehner 1994) and the eastward extension of the Shepody Fault, herein named the Shepody–Beckwith Fault (Plates 4, 5). The Shepody–Beckwith Fault truncates most of the north limb of the Hard Ledges Syncline immediately south of the Grande Anse type section (Fig. 71, section A–A'). The south limb of the syncline (equivalent to the north limb of the Maringouin Anticline) is still preserved in New Brunswick but is entirely cut out to the east, in Cumberland Bay and western Nova Scotia, indicating significant displacement along the fault. Boss Point strata dipping steeply south are preserved on the north limb of the syncline and are affected by a pervasive flat fracture for about 700 m south of the fault trace.

The close to tight folds in the Boss Point and Grande Anse formations at Johnson Mills on the south side of the Shepody–Beckwith Fault contrast sharply with the gently dipping monoclinal section of Grande Anse Formation on the north side of the fault (Fig. 71, section A–A'). A possible explanation for this contrast is that the succession on the north side was 'sheltered' from the strain to the south. Thus, the Grande Anse Formation and the subjacent Boss Point Formation north of the fault are lying on a hard basement block, the western extension of the Hastings Uplift.

The uplift was encountered at a depth of 2.8 km in Hastings No. 1, a well drilled east of Amherst (Fig. 6) in Nova Scotia by Gulf et al. (Howie 1986). No rocks of the Windsor or Mabou groups were intersected on the Hastings Uplift in the well; nor are they likely present on the uplift in New Brunswick. Their absence is suggested by a strong, 2940 gamma aeromagnetic anomaly at Cape Station on the west side of Shepody Bay (Geological Survey of Canada 1958). The anomaly indicates that crystalline basement is either at the surface or shallowly buried. No outcrops could be found to confirm this; regardless, the anomaly precludes the existence of a thick 'Carboniferous' succession. The basement at Cape Station is interpreted as the western end of the Hastings Uplift and effectively separates the Cumberland Subbasin from the Sackville Subbasin (Fig. 84).

The south side of the Cape Station basement is faulted against the Hopewell Cape Formation along the north splay of the Shepody–Beckwith Fault that apparently follows the north side of the valley along Hamilton Creek (Fig. 84; Plate 4). The existence of the fault is indicated by 1) erratic bedding attitudes in conglomerate outcrops of the Hopewell Cape Formation along Hamilton Creek, 2) Boss Point rocks on the west side of the Harvey–Hopewell Fault striking south into the Hopewell Cape Formation, and 3) juxtaposition of the basement slice along the upper part of Hamilton Creek against the Boss Point Formation on the northeast side of the break. The geometry of the rock units along Hamilton Creek implies that the splay of the Shepody–Beckwith Fault has right-lateral and down-to-the-south components of movement. The displacement postdates the early Westphalian A (Langsettian) Boss Point Formation.

A fault on the west side of Shepody Bay at Hopewell Hill and Shepody Marsh is considered to be a second, south splay of the Shepody–Beckwith Fault (Plate 4). The splay has the distal Lime-kiln Brook and Maringouin formations on its south side and the proximal Hopewell Cape Formation at Shepody Mountain on its north side. It is interpreted as a north-vergent reverse or thrust fault. It represents an inversion structure resulting from the succession of the Cumberland Subbasin being squeezed into the 'corner' created by convergence of the Caledonia and Hastings basement blocks.

Summary, Cumberland Subbasin Structure

The tectonic history along the northwestern side of the Cumberland Subbasin in New Brunswick is evidenced by the depositional and structural architecture of the Carboniferous Windsor, Mabou, and Cumberland groups and by the Mesozoic Fundy Group. The development of substantial accommodation space during Windsor and Mabou time is shown by thick successions of Windsor evaporites (including rock salt) and coarse proximal conglomerates of the Hopewell Cape Formation. The development indicates a prolonged period of extensional or transtensional down-to-the-basin subsidence along the ancestral basin margin (Harvey–Hopewell Fault) and possibly the Shepody–Beckwith Fault. Inversion and uplift of the Windsor and Mabou successions is demonstrated by a mid-Namurian depositional break (disconformity and/or unconformity) that predates the regionally distributed latest Namurian–early Westphalian Cumberland Group.

Late Namurian renewed subsidence of the Cumberland Subbasin is shown by a very thick succession of Cumberland rocks that reaches 4 km at the type section at Joggins, Nova Scotia (Ryan and Boehner 1994). The original depositional (postlithification) thickness of the Cumberland Group along the northwestern side of the Cumberland Subbasin is not known. Only the basal beds of the group (lower members of the Boss Point Formation) escaped erosion in New Brunswick. Adjacent to the Caledonia Uplift, the Boss Point Formation comprises fairly coarse quartz-clast conglomerates and sandstones of the Breau Creek Member, which give way to the southeast to finer grained grey sandstone and mudstone of the Ward Point Member. However, the lithologically distinctive maroon, ripple-laminated sandstone and mudstone unit (Chignecto Bay Member) underlying both the Breau Creek and Ward Point members demonstrates the unlikelihood of an abrupt lateral demarcation between the Breau Creek and Ward Point lithofacies. It is therefore probable that the northwestern side of the Cumberland Subbasin was not controlled by a basin-bounding fault during Cumberland time. Instead, the depocentre subsided by regional downwarping.

In the Cumberland Subbasin of Nova Scotia, the Cumberland Group is unconformably succeeded by the Pictou Group, as evidenced by the Malagash Formation cutting out the Ragged Reef Formation, thereby lying on the Boss Point Formation on the northern limb of the Tatamagouche Syncline (Ryan and Boehner 1994, their Map 90-13). Following deposition of the late Westphalian–Early Permian Pictou Group, the Cumberland Subbasin underwent a major period of compression or transpression that produced inversion of the Windsor Group and younger strata. The inversion and section-shortening was accomplished primarily via a system of reverse and thrust faults along the northwestern and northern margins of the subbasin. The Harvey–Hopewell, Shepody–Beckwith, Dennis Beach, and Lockhart Lake faults form an imbricate system of southeast-dipping structures that telescopes the Windsor, Mabou, and Cumberland groups against the Caledonia and Hastings basement uplifts in New Brunswick.

The exhumation of lenticular sulphate bodies (Windsor Group) along the soles of the hanging walls of those reverse faults suggests a regional décollement in the fairly incompetent evaporites of the Windsor Group (Webb 1963). The mobility of salt during the inversion, or as a facilitator of inversion, is indicated by the intrusion of salt of the Pugwash Mine Formation into the Pictou Group in the eastern Cumberland Subbasin (Howie 1986, 1988; Ryan and

Boehner 1994). The anomalously steep dips and folds in the Mabou and Cumberland groups from Rocher Bay notheastward to Maringouin Peninsula are interpreted to have resulted largely from salt mobility and decoupling of the succession above the level of the Windsor evaporites.

The Paleozoic strata in the Cumberland Subbasin are displaced to an unknown degree by late faults that transect the Triassic to Jurassic Fundy Group. On the north side of Rocher Bay near Waterside, redbeds of the Fundy Group are faulted down against the Mabou and Cumberland groups (Plate 6). Those faults constrained and preserved the Fundy Group (Flaherty and Norman 1941; Webb 1963) and apparently are extensional reactivations of older Carboniferous compressional structures such as the Dennis Beach and Lockhart Lake faults.

SACKVILLE SUBBASIN STRUCTURE

The name 'Sackville Subbasin' was introduced by Martel (1987) to describe a structural basin separate from the Cumberland Subbasin. He defines the northwestern and northeastern boundaries of the subbasin with the Westmorland Uplift as the Dorchester and Port Elgin faults, respectively (Fig. 84). The western boundary of the subbasin with the shallowly buried Caledonia Uplift is delimited by the Harvey–Hopewell Fault, and the southern flank with the buried Hastings Uplift is marked by the Wood Creek Fault. The Tantramar Fault and Sackville Syncline are two noteworthy intrasubbasinal structures. The former is a significant late northeast-trending extensional fault, associated with the collapse of cap rocks above rock salt of the Pugwash Mine Formation inverted along the Hastings Uplift via the Wood Creek Fault (Plate 5).

Harvey–Hopewell Fault

The Harvey–Hopewell Fault from Cape Station to Upper Dorchester (Fig. 84; Plate 4) defines the western margin of the Sackville Subbasin with the condensed Late Carboniferous cover sequence lying upon the buried eastern end of the Caledonia Uplift. It is the northeastern continuation of the same fault described earlier under ***Cumberland Subbasin Structure***. Evidence of Late Carboniferous northwest-directed compression on this segment of the fault is indicated by the presence of a footwall syncline on the west side of the basement block at Cape Station. Northeast of there from Demoiselle Creek to Beaumont, the Boss Point Formation adjacent to the fault trace dips toward the fault, suggesting that a footwall syncline was overridden by the advancing thrust. Sulphates are exposed on the hanging wall at the leading edge of the thrust at Lower Cape. The Harvey–Hopewell Fault system inverted the Sackville Subbasin succession over the eastern end of the Caledonia basement block, facilitated by the sulphates and probably rock salt in the deeper subsurface.

Farther to the northeast at Upper Dorchester, limestone and gypsum of the Lime-kiln Brook Formation are faulted against oil shales of the Albert Formation. The fault is exposed in a small disused limestone quarry on the east side of Highway 106. St. Peter (2001) uses structural and stratigraphic relationships in that quarry, in conjunction with lithologs from Wells 325 and 330 (Fig. 32), to interpret the history of the Harvey–Hopewell Fault. By using cross-sections showing reconstructions during Windsor, Mabou, and Cumberland time, and post-Cumberland reactivation, St. Peter (2001, his Fig. 4) presents evidence of an early down-to-the-southeast extensional phase along the fault that enabled deposition in the Sackville Subbasin during Windsor and Mabou time. The extensional phase was followed by a period of relative dormancy on the fault during Cumberland time, as implied by the unchanged lithofacies within the Boss Point Formation across the fault line. Reverse reactivation of the southeast-dipping structure in post-Cumberland time together with post-Carboniferous erosion led to the present exhumation of the Lime-kiln Brook and Hopewell Cape formations on the hanging wall at Upper Dorchester.

The fault plane in the Upper Dorchester quarry (mentioned above) between the Albert and Lime-kiln Brook formations is not well exposed but appears to be a steep, southeast-dipping surface. This inference is supported by evidence in shallow coreholes (Wells 369–376) put down in and adjacent to the quarry. The trend of the fault trace bends quite sharply from northerly along Memramcook River to northeasterly at Upper Dorchester and Woodhurst. This shift, together with the steepness of the fault at the quarry, suggests that slip movement on the fault may have changed from dominantly dip slip on the north-trending part to mainly oblique slip or strike slip on the northeast-trending leg. The change in the dominant slip vector, coincident with the bend in the fault trace, implies that the northeastern leg along the south side of the Westmorland Uplift (Fig. 6), where the fault apparently merges with the Dorchester Fault, has a right-lateral component of displacement.

The north-trending, gently folded syncline in the Boss Point Formation that occurs north of Beaumont has an axial strike nearly parallel to the trace of the adjacent Harvey–Hopewell Fault, suggesting the two structures are genetically related.

Dorchester Fault

The Dorchester Fault defines the northwestern boundary of the Sackville Subbasin from the Harvey–Hopewell Fault in the west to the Port Elgin Fault in the east (Martel 1987). The approximately 15 km segment of the Dorchester Fault extending eastward from the termination of the Harvey–Hopewell Fault at Upper Dorchester marks the boundary between the Moncton and Sackville subbasins. The remaining, easternmost segment of the Dorchester Fault is interpreted as the boundary between the Sackville Subbasin and crystalline rocks of the Westmorland Uplift (Fig. 84).

In Well 709, which lies north of the Dorchester Fault and east of the Memramcook East Fault, 1508 m of McQuade Brook Formation was drilled below the unconformably overlying Boss Point Formation. This demonstrates a thick sequence of Horton Group in that area, supporting the interpreted continuation of the Moncton Subbasin east of the Memramcook East Fault (Martel 1987, his Fig. 3).

As described earlier under ***Eastern Moncton Subbasin Structure***, a controversy exists as to whether the Dorchester Fault tracking east of Upper Dorchester along the north side of the Sackville Subbasin is dominantly a compressional north-dipping reverse-thrust fault (as per Gussow 1953) or a south-dipping extensional normal fault (as per Martel 1987). Exposure in the Upper Dorchester area is insufficient to determine whether the southeast-dipping Harvey–Hopewell Fault, with its history of early down-to-the-basin extension and later south-over-north inversion, overrides the northwest-dipping Dorchester Fault, or vice versa. Both faults have post-Cumberland reverse displacement. They appear to converge east of Upper Dorchester as they close around the 'nose' of the Caledonia basement, which lies shallowly buried beneath the peninsula at Beaumont (Fig. 84). The configuration of the boundary between the Westmorland Uplift and the Sackville Subbasin depends on which of the two faults achieved dominance east of Upper Dorchester.

Port Elgin Fault

The Port Elgin Fault (Fig. 84) is a northwest-trending break named by Martel (1987). South of its intersection with the Dorchester Fault, the Port Elgin Fault defines the northeastern boundary of the Sackville Subbasin with the Westmorland Uplift. Prior to the work by Martel, the subsurface existence of the fault was suspected on the grounds of the contrast in sequences cut by adjacent Wells 400 and 402 just north of Port Elgin (Plate 2). Well 402 on the footwall intersected basement granite at a depth of 890 m, whereas Well 400 on the hanging wall terminated at 991 m while still in the Boss Point Formation (Fig. 55). Martel (1987) used records from both wells in addition to public seismic reflection profiles from a joint Chevron Canada Resources Limited–Irving Oil Limited program in the early 1980s to demonstrate key features of the Port Elgin Fault.

The fault is a down-to-the-basin west-dipping extensional structure. This is shown in part by the depth of the contact between the Boss Point and Salisbury formations. The contact is 232 m deeper in Well 400 than in Well 402 (Fig. 55), which also suggests that the fault underwent post-Salisbury movement. Too few outcrops exist near the fault's possible surface trace to determine whether it displaces the Richibucto Formation. Reflectors assignable to the Pictou Group appear to pass over the subcrop location of the fault (see Martel 1987, his Fig. 4) without being affected. A succession of Horton and/or Sussex group strata up to 2.5 km thick exists in the Sackville Subbasin adjacent to the fault. The overlying Windsor and Mabou groups comprise an additional 2 km of rocks. Thus, the Port Elgin Fault was a major Early Carboniferous (pre-Cumberland Group) growth fault controlling the eastern part of the Sackville Subbasin, giving it a history analogous to that interpreted by St. Peter (2001) for the extensional early history of the Harvey–Hopewell Fault.

Wood Creek Fault

The trace of the Wood Creek Fault between Grande Anse and Wood Creek (Plate 5) was first mapped by Johnson (1997). Gussow (1953, his Fig. 5) placed a question mark beside a fault he thought might occur at Wood Creek but reported nothing in his text to support the existence of the fault. The fault line in New Brunswick and its suspected location in Nova Scotia is based on a number of constraints. In New Brunswick sharp contrasts in bedding attitudes and obvious terminations of formations are apparent along its trace. An outcrop of Boss Point Formation on the north side of Wood Creek is the closest exposure to the interpreted location of the trace. Bedding there dips anomalously steeply at 60° to the north.

Gussow (1953, his Fig. 5) considered the northern contact of the Grande Anse Formation an unconformity with the adjacent Windsor, Mabou, and Cumberland groups (Plate 5). That interpretation is questioned herein. The Grande Anse Formation dips consistently at 10° to 15°N between the trace of the Shepody–Beckwith Fault and the Grande Anse area.

Therefore, too much section and too little space exist south of the older units, which are exposed to the north, to fold the section into an east-trending syncline without a fault being present. Because older formations lie on the northwest side of the Wood Creek Fault, the northwestern block is interpreted as the upthrown side.

The location of the fault is also indicated to a degree by negative gravity anomalies along its northwestern side (Gussow 1953, his Fig. 13; Hassan 2000, p. 74–75). A small negative anomaly occurs at Johnson Creek and a much larger one at the head of Cumberland Basin east of Westcock. The latter extends in a northeasterly direction approximately along the surface trace of the Tantramar Fault to the Halls Hill area (Plate 5). A northwest–southeast seismic line (29Y of the 1984 Chevron–Irving program) passed over the Tantramar Fault in the Upper Point de Bute area but did not continue far enough southeast of Fort Cumberland Ridge to cross the interpreted surface trace of the Wood Creek Fault. However, its seismic profile does image a large seismically transparent (salt?) body that rises to within 800 m of surface. Consequently, the negative gravity anomalies are interpreted to result from subsurface rock salt of the Pugwash Mine Formation. The salt body interpreted to lie beneath Fort Cumberland Ridge would in part occur below the upturned section of Boss Point Formation on the southeast side of the Tantramar Fault. The salt body may continue to the southeast, where it lies against the footwall of the northwest-dipping Wood Creek Fault. The reversal in bedding dip across the Tantramar Fault is believed to reflect a former salt-cored anticline, the hinge of which was broken and offset by the Tantramar Fault. Possibly the only vestige of the original anticlinal hinge zone lies in the interpreted (but unexposed) Mabou Group at the head of Cumberland Basin. The fold could represent a hanging-wall anticline to the Wood Creek Fault.

The argument was made earlier (under ***Shepody–Beckwith Fault***) that basement rocks of the Hastings Uplift probably form the foundation below the Grande Anse and Boss Point formations on the north side of that fault on Maringouin Peninsula. The evidence cited is the general absence of deformation in the Grande Anse Formation and the postulated presence of exposed basement at Cape Station. Analogously, the beds along the north side of the Wood Creek Fault dip more steeply than do those to the south, making it feasible to interpret the Wood Creek Fault as the northern structural boundary of the Hastings Uplift. Therefore, the northern boundary of the Hastings Uplift basement block (including, by inference, the southern boundary of the Sackville Subbasin) does not follow the line tentatively suggested by Howie (1986, his Fig. 5; Howie 1988, his Fig. 46) or Martel (1987, his Fig. 2). Instead, it lies considerably farther northwest at the Wood Creek Fault. This alternative interpretation means that the southern margin of the Sackville Subbasin is analogous to the northern margin of the Cumberland Subbasin (Howie 1986; Ryan and Boehner 1994), in that both are flanked by welts of salt inverted along basin-bounding master faults.

The Wood Creek Fault is likely offset at the head of Cumberland Basin by a west-northwest-striking cross fault with an implied right-lateral displacement (Plate 5). Although the Wood Creek Fault could bend sharply and remain unbroken at the head of Cumberland Basin, the structural relationships in a small quarry near British Settlement imply the existence of a fairly major fault in that area. Along the southwestern quarry wall, grey sandstones of the Boss Point Formation dip at 80° to 90°NNE. The same grey beds occur in the quarry floor, but immediately to their northeast are outcrops of red sandstones interpreted as Salisbury

Formation. The Boss Point and Salisbury beds in the quarry floor are overturned and dip 70°SSW. On the northeastern low bank of the quarry, red sandstones of the Salisbury Formation dip 30°N. A concealed interval several metres wide between the overturned beds in the quarry floor and the shallowly dipping beds on the northeast bank is believed to hide a significant west-northwest-trending fault (Plate 5).

Tantramar Fault

The Tantramar Fault was first named and described by Gussow (1953, his Fig. 5, 6). He identified it from a negative gravity anomaly and steep dips in the Boss Point Formation adjacent to its interpreted trace. He interpreted it as a southeast-dipping reverse fault, partly because older strata appear on its southeastern side (see also Johnson 1997) and partly because he viewed it as an extension of the Harvey–Hopewell Fault. Seismic line 29Y (see ***Wood Creek Fault***, above) crosses the Tantramar Fault at Upper Point de Bute. It is interpreted to show that the Tantramar break dips steeply to the northwest and is thus an extensional down-to-the-basin fault. On the basis of the seismic profile and surface geological relationships, the net dip slip on the Boss Point–Salisbury contact at Upper Point de Bute is estimated at about 1.5 km. The throw is suspected to decrease to the northeast as the volume of the associated salt body decreases. For example, a seismic line along Highway 970 that crosses the trace at Baie Verte (Plate 5) shows minimal displacement of the Richibucto Formation.

The relationship of the Tantramar Fault to the Wood Creek Fault is similar to that of the normal faults southeast of and on the hanging wall of the Harvey–Hopewell Fault at Chemical Creek and Lower Cape (Plate 4). They appear to be later extensional structures postdating the inversion implicit on the accompanying basin-bounding, reverse-thrust structures.

Sackville Syncline

The Sackville Syncline, or Dorchester Syncline of Gussow (1953), is a gentle to open, gently northeast-plunging fold. It follows the trend of the northeast axis of the Sackville Subbasin and is identifiable from Dorchester Cape in the west to Baie Verte in the northeast. Its axis is approximately parallel to the Tantramar Fault. The southern limb is cut by the Tantramar and Wood Creek faults. Seismic profiles strongly suggest that the hinge zone of the syncline is coincident with the thinnest part of the Windsor Group succession. It is likely that the location of the syncline was controlled by the mobilization and withdrawal of salt of the Pugwash Mine Formation toward the northwestern and southeastern structural boundaries of the Sackville Subbasin (e.g., see Martel 1987, his Fig. 3). The flowage of salt as a causative factor for regional fold development in the Maritimes Basin was previously advanced by Williams (1974, his Fig. 12) and Ryan and Boehner (1994, p. 108).

Summary, Sackville Subbasin Structure

The structural history of the Sackville Subbasin is very similar to that of the Cumberland Subbasin. Seismic reflection profiles and the data from Wells 325 and 716 (Plate 5) demonstrate that the Horton Group and possibly the Sussex Group lie unconformably below the Windsor Group in the subsurface of the Sackville Subbasin (Martel 1987). The pre-

Windsor history of the basin is poorly known. Presumably, it involved periods of subsidence along basin-bounding growth faults to accommodate Horton and Sussex sedimentation in a fashion similar to that in the Moncton and Cocagne subbasins. An angular unconformity at the base of the Windsor Group indicates a phase of compression or transpression, culminating in the inversion and partial erosion of the Horton and Sussex groups (Martel 1987, his Fig. 7).

Thick successions of Windsor carbonates and evaporites and Mabou redbed clastics attest to renewed subsidence along the basin-bounding Harvey–Hopewell, Dorchester, and Port Elgin faults. It is not known if the Hastings Uplift was an active provenance area, and by corollary, if the Wood Creek Fault was an escarpment during Windsor and Mabou time. Post-Mabou compressional reactivation of the Harvey–Hopewell and Dorchester faults is demonstrated by angular discordance between strata of the Mabou and Cumberland groups and by the intervening spore-indicated mid-Namurian time break.

Like the Cumberland and other subbasins in the Maritimes Basin of New Brunswick, the Sackville Subbasin apparently subsided due to regional downwarping during Cumberland time. The absence of any lithofacies change in the Boss Point Formation across the Harvey–Hopewell and Dorchester faults implies that those faults were largely dormant during deposition of the Cumberland Group (St. Peter 2001). Post-Cumberland inversion of the basin fill is evident from reverse-thrust displacement on the Harvey–Hopewell Fault and the juxtaposition of Windsor sulphates against Boss Point rocks at Lower Cape and against Albert oil shales at Upper Dorchester. The latest movement on the Dorchester Fault appears to largely predate deposition of the Pictou Group (Salisbury Formation). On the other hand, inversion of the succession on the southeastern side of the Sackville Subbasin via the Wood Creek Fault is later and postdates the late Westphalian–Stephanian Richibucto Formation. As in the Cumberland Subbasin, the post-Pictou inversion of the Sackville Subbasin was likely facilitated by a décollement surface in the Windsor evaporites. The presence of diapiric salt bodies along the Harvey–Hopewell, Dorchester, and Wood Creek faults suggests that the salt flowed kinematically, or was assisted by tectonic translation from the axial part of the basin to the basin margins, where it was impounded against the basement blocks of the Westmorland and Hastings uplifts.

Inversion of the basin fill was followed by a relaxation of stress. This is indicated by interpreted normal displacement on the Tantramar Fault, a dislocation that closely follows the crest of a northeasterly trending subsurface ridge of salt of the Pugwash Mine Formation. The late extension may be in part as late as Mesozoic, a possibility suggested by analogy with the structural setting of the Fundy Group at Rocher Bay in the Cumberland Subbasin.

CHAPTER 4

ECONOMIC GEOLOGY

INTRODUCTION

Rocks of the Maritimes Basin in the report area have provided economic quantities of oil and natural gas, gypsum, copper, and building stone over the last two centuries. Numerous deposits and encouraging occurrences of oil shale, uranium, lead, and zinc have also been investigated. The following account of these commodities is not exhaustive but is intended to place known and potential energy and mineral resources within the stratigraphic and structural framework established in the preceding chapters.

ENERGY RESOURCES

Hydrocarbon resources in the area include oil and natural gas, oil shale, and coal.

Oil and Natural Gas

Oil seeps in exposed sandstone beds of the Albert Formation between Stoney Creek and Saint-Joseph have been known for more than 150 years (Clapp 1915, p. 44). They were the lead followed by Dr. H.W.C. Tweddle, manager of Standard Oil Works of Pittsburgh (Martin 2003), when he drilled four shallow wells near Dover in 1864 (Hume 1932). From 1901 to 1906, approximately 70 shallow wells were put down in the Albert Formation between Dover and Saint-Joseph and produced about 3000 barrels of oil (Howie 1968; Foley 1989; St. Peter 1992). However, not until 1909 did Maritime Oilfields Ltd. make its significant gas and oil discovery on the west side of Petitcodiac River (Clapp 1915; Hume 1932; Henderson 1940). That discovery, the Stoney Creek Field (Fig. 6), produced about 804,000 barrels of oil and 30 billion cubic feet (bcf) of sweet gas from the time of discovery until 1991, when the last producing gas wells were shut in (see below).

From 1909 until 1986, 156 wells were drilled in the Stoney Creek Field by a number of operators (St. Peter 1992). The wells delineated a reservoir in the Albert Formation with an east–west strike length of about 4 km and a north–south dip dimension of about 2 km (Henderson 1940; Foley 1989). Drillers of the early wells developed a local stratigraphic nomenclature for the grey strata they considered to be 'Albert Formation' (Henderson 1940). Their system entailed dividing the grey beds informally into six 'sands' designated as 'sands I to VI.' The four upper sands lie in the Hiram Brook Member and are in fact packages of sands of varied thickness separated by zones of grey shales, kerogenous shales, and siltstones (Table 6). Sand V is actually kerogenous shales and kerogenous mudstones of the Frederick Brook Member, and sand VI is the main sand body in the Dawson Settlement Member. (See earlier discussion under ***Hiram Brook Member***.) The early wells, drilled by cable-tool rigs, were left uncased below the uppermost producing sand package. However, it was recognized that nearly all natural gas production derived from the updip part of sands III and IV, and that the oil came from the downdip, southeastern part of the field in sand VI.

Irving Oil Limited holds the production lease for the Stoney Creek Field. In 2005 Irving assigned operatorship to Contact Exploration Inc., a junior exploration and production company from Calgary, Alberta. Contact shot a three-dimensional seismic program over the field and contiguous area. The company thereafter (2006) used historical Stoney Creek well records and the interpreted seismic data to determine where to drill two horizontal (directional) wells in the oil-producing sand VI (Fig. 89).

In the same year, Contact initiated a program to re-enter 30 shut-in wells to assess their potential for further production and to evaluate zones possibly bypassed during earlier production. Slotted liners and heat strings were placed in the open-hole sections of the two horizontal wells. Contact began production from the two horizontal wells in 2007. It also undertook workovers on 14 of the old vertical wells and augmented oil production by bringing four of the historical wells back on stream. The workover program demonstrated that the reservoir is structurally compartmentalized and that some areas of the field have not been exploited. In mid-2007 Contact announced an independent assessment of the field and cited proven and probable reserves at Stoney Creek of 1.2 million barrels of oil and 6.5 bcf of natural gas.

A detailed geology description of the Stoney Creek Field lies beyond the scope of this report. Henderson (1940), Howie (1968), and Foley (1989) provide excellent and comprehensive data on the thickness, continuity, porosity and permeability of the reservoir sandstones. However, the present authors have made two noteworthy discoveries concerning the trapping mechanism at Stoney Creek.

- First, the grey strata at the Stoney Creek Field that the original drillers and subsequent investigators (Henderson 1940; Howie 1968; Foley 1989) assigned to the Albert Formation are in part Gautreau Formation as well as Albert Formation. The Gautreau Formation comprises the bluish grey or greenish grey shales, and minor limestone and sulphate beds that lie above the brown kerogenous shales, kerogenous mudstones, and micaceous sandstones that characterize the Albert Formation (Table 6). The seal at Stoney Creek, at least for the eastern part of the field, is the thick shales of the Gautreau Formation and the overlying red mudstones of the Weldon Formation (Fig. 13, 14). Henderson (1940, p. 173) contended that individual sandstone bodies were each sealed by a thoroughly cemented cap of very fine-grained sandstone.

- Second, the lacustrine and fluvial reservoir sandstones and intervening lacustrine shales of the Albert Formation are limited to the west and northwest by a dramatic facies change into coarse, immature, alluvial conglomerates and lithic sandstones of the Steeves Mills Formation (Fig. 13, 14).

Gas and oil exploration in the eastern Moncton Subbasin has been fairly continuous since the mid-1980s (St. Peter and Spady 2003). From 1985 to November 2008, 18 exploration wells were drilled outside the Stoney Creek lease. In 1985 Chevron Canada Resources Limited and Irving Oil Limited made a significant gas discovery in the Albert Formation in their Well 333. ***(See Appendix 1 for details about this and all other numbered wells cited in Chapter 4.)*** The well was later plugged and abandoned, but in 1998 the encouraging result led MariCo Oil and Gas Corporation to drill an offset well (Well 689) from the Well 333 pad (Fig. 90). Flow tests

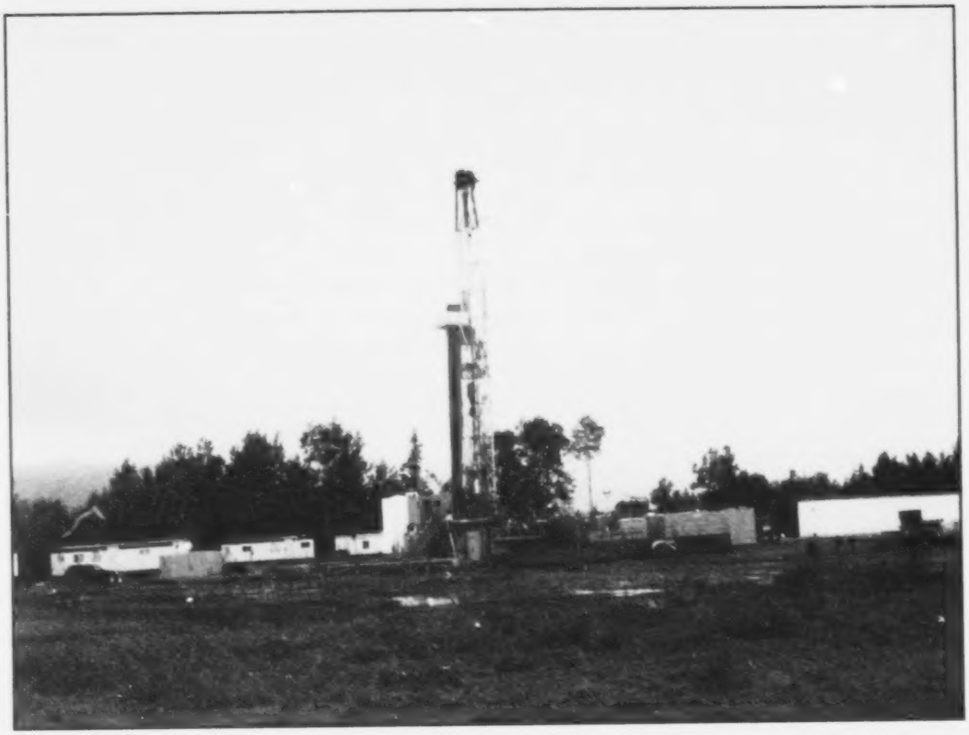

Figure 89. Drilling of the I-88 directional well (Well 749) of Contact Exploration Inc. in the Stoney Creek Field.

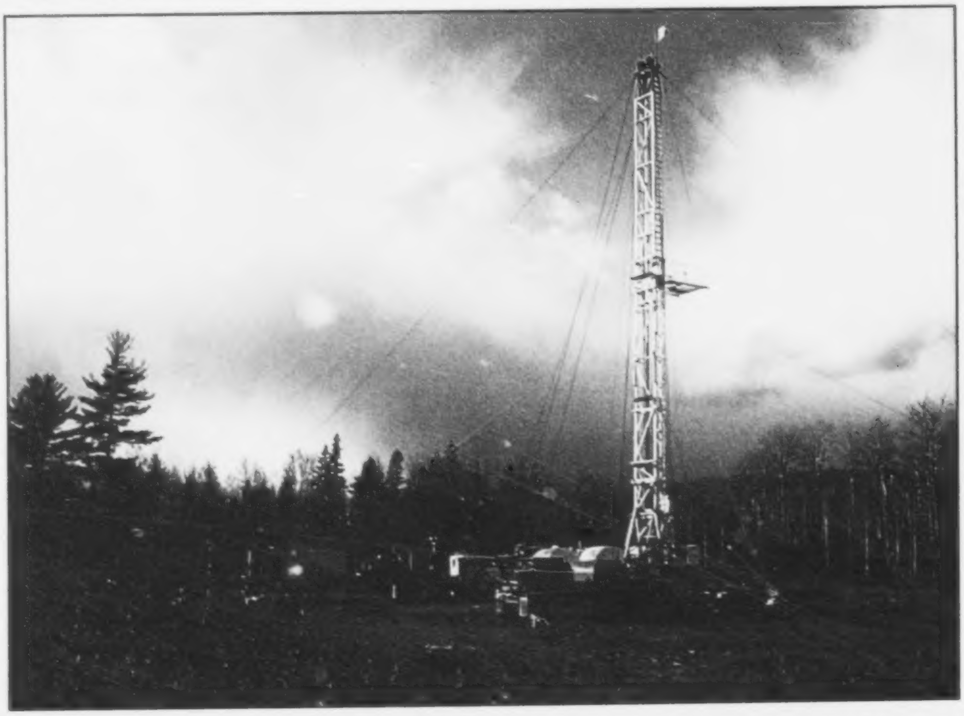

Figure 90. The Downey No. 1 (Well 689) of MariCo Oil and Gas Corporation near Hillsborough.

indicated an initial production of 1 million cubic feet per day (mmcf/day) from Well 689; however, the well was never brought into production and is presently shut in.

The gas and oil rights west and southwest of the lease in the Stoney Creek Field are presently held by PetroWorth Resources Inc., a junior exploration company with offices in Calgary and Toronto. The company made an encouraging gas discovery just north of Dawson Settlement in its second well (Well 765), which was drilled in late 2007 about 200 m north of Well 317. In August 2008 the company announced that, following fracture completion of two prospective intervals in the Albert Formation, the well flowed gas at a rate of 1.058 mmcf/day. The company's third well, Well 790 drilled in June 2008, is situated about 1.3 km east of Well 765 and encountered two gas-bearing zones. Further details have not yet been released on this well.

Prior to the recent exploration work by Contact and PetroWorth, Columbia Natural Resources Canada Limited (CNRC) held most of the prospective gas and oil lands in the eastern Moncton Subbasin. In 2000 CNRC drilled six exploration wells alone or with partners in that area (Wells 704–709; Plates 4, 5). In Well 708 near Edgetts Landing, the company demonstrated the potential extent of a earlier, promising oil discovery in the Albert Formation. (That discovery was made in 2000 by MariCo Oil and Gas Corporation in Well 703, also at Edgetts Landing.) Columbia undertook test production on Well 708 and reported an initial rate of 40 barrels per day.

Wells 703 and 708 are presently shut in. The two wells are located on an east-northeast-trending, faulted anticline that has been partly imaged by two-dimensional seismic lines (Wilson 2002, his Fig. 11). The anticline lies on the north side of the Wilson Brook Fault. Part of the fold is exhumed, as evidenced by exposures of the Albert Formation at Frederick Brook, Boudreau Village, Taylor Village, and Upper Dorchester (Plate 4). The Edgetts Landing oil play will likely require a three-dimensional seismic survey before further drilling takes place.

Shale Gas

Shale gas is rapidly becoming a major contributor to the North American gas market. The best known deposits are the Barnett Shale in the Fort Worth Basin of west Texas, Fayetteville Shale in the Arkoma Basin of Arkansas, Woodford Shale of Oklahoma, and Marcellus Shale in the Appalachian Basin of Virginia, Ohio, Pennsylvania, and New York. The Barnett Shale is the second-largest onshore domestic gas field in the United States and provides 8% of America's natural gas supply (Barnett Shale Newsletter 2008). The two largest companies in the Fayetteville play reported a combined expenditure of greater than $1.5 billion on shale development for 2007 (Arkansas Geological Survey 2009). More than 1500 wells were drilled in the Woodford Shale of southeastern Oklahoma. Between 2003 and the end of 2007, 375 wells were drilled in the Marcellus Shale in Pennsylvania (Geology.com. 2009); the formation is estimated to hold an in-place resource of an incredible 500 trillion cubic feet.

The enormous potential of organic-rich shales to yield economically viable natural gas has not escaped the attention of the two largest holders of oil and natural gas rights that are presently exploring in the report area. Contact Exploration Inc. and PetroWorth Resources Inc. are both assessing the shale gas potential of the highly kerogenous Frederick Brook Member of the

Albert Formation. To this end, Contact and their operator, Triangle Petroleum Limited, carried out a 30 km, two-dimensional seismic survey on their Beech Hill shale prospect in the summer of 2008 (Contact Exploration Inc. 2009). Their licence lies immediately south and east of the Stoney Creek lease. The Frederick Brook Shale is widely distributed in the subsurface of the eastern Moncton Subbasin. It appears in thicknesses up to 350 m and, in most places where reasonably measurable, exceeds 200 m thick (see ***Frederick Brook Member*** in Chapter 2). Organic maturation data from surface and well samples demonstrate that, in the deeper part of the eastern Moncton Subbasin, the Frederick Brook Member lies within the gas zone (MacIntosh and St. Peter 2005) and is thus a prospective source of shale gas.

Corridor Resources Inc. is a Halifax-based junior gas and oil exploration and production company that presently holds a producing natural gas lease at the McCully Field (Fig. 6) near Sussex in the western Moncton Subbasin. Corridor, along with its partner, PCS New Brunswick Division, is actively drilling and producing gas from the field. Most of the gas is from fracture-completed tight sand zones in the Hiram Brook Member of the Albert Formation that are similar to the sandstone intervals in the same member at the Stoney Creek Field. Corridor and PCS have also successfully fracture-completed, and are producing gas from, organic-rich shale of the Frederick Brook Member in the McCully F-58 well.

In late 2007 Corridor announced that three small fracs and an acid squeeze had been undertaken in the Frederick Brook Member in the McCully F-58 well (Fig. 91) as part of an extended program to determine the best techniques for producing gas from shale, commonly a lengthy process in a new area (Corridor Resources Inc. 2007). After conducting an acid squeeze on all perforated intervals in the Frederick Brook Member and following a cumulative flowing time of 133.5 hours, the company reported that the shale produced gas at a total rate of 247 thousand cubic feet per day (mcf/day). Available production records indicate that the shale has a stable yield of about 200 mcf/day from end March to end July 2008. However, 6000 barrels (61%) of frac fluids remained in the fracture system, restricting natural gas production. The frac fluid was expected to clean out over time.

Continuing from their shale gas success at McCully, Corridor announced in August 2008 that the company will undertake a 65 km^2 three-dimensional seismic program and sink three widely spaced vertical shale gas coreholes in 2009 on the south side of the Moncton Subbasin near Elgin (Fig. 6). The vertical wells will be followed by a horizontal well to test the Frederick Brook Shale for a length of about 1000 m. Cores and logs will be evaluated for lithology, porosity, permeability, organic content, and thermal maturity to assess the best location for shale gas production.

Oil Shale and Albertite

High-grade oil shale was known to local people in Albert County prior to 1839 when the first provincial geologist, Abraham Gesner, visited a rumored oil shale site south of Baltimore near Caledonia Mountain. There, Gesner heard stories of shale rock being used to make fires for maple syrup production (Martin 2003, p. 39). During his survey of Frederick Brook in the following year, Gesner observed even more impressive oil shales bearing what was thought to be a 'coal seam.' A much larger 'seam' was discovered in 1849 by John and Peter Duffy following erosion created by the bursting of a dam on Frederick Brook (Dawson 1868; St.

Peter 1992; Martin 2003). The seam was subsequently determined to be a cross-cutting vein of solid bitumen that acquired the name 'albertite.' Gesner succeeded in distilling oil (kerosene) from albertite in the 1840s and in so doing earned the moniker 'Father of Petroleum Geology.' The albertite vein at Frederick Brook became the site of a prosperous mine that operated commercially from the middle 1850s until resource depletion in 1881. Albertite yields about 100 gal/ton of oil (500 L/t). Most of the albertite was shipped to cities in New England where it was refined and used for fueling street lamps. The oil shales that form the host rock of the albertite, like the bitumen vein itself, have had a long history of exploration and attempted development, the early history of which is described in colourful detail by Martin (2003). The later, 20th-century history of oil shale exploration drilling and feasibility studies is outlined in Macauley et al. (1985) and St. Peter (1988; 2000b).

The highest grade oil shales occur in the medial part of the Albert Formation, the Frederick Brook Member. As noted above under ***Shale Gas***, the Frederick Brook Member in the eastern Moncton Subbasin can reach up to 350 m in thickness and exceeds 200 m thick in most places. The Albert shales have been determined as the thickest and the highest grade oil shales known in Canada and consequently are the first shales most likely to achieve commercial development (Macauley 1981; Macauley et al. 1985).

The Frederick Brook Shale has been the subject of several programs of drilling, trenching, and organic geochemical assessment over the years. The exploration work has primarily focused on four districts where high-grade beds are exposed: near Rosevale, Frederick Brook, Taylor Village, and in the Dover–Saint-Joseph area. Details of the exploration efforts are provided in Alcock (1948a, 1948b), Timm et al. (1948), Macauley and Ball (1982), Wright (1982), Brown and Whaley (1986), St. Peter (1988, 2000b), and Lynch (1999). The main oil shale areas at Rosevale, Frederick Brook, and Dover are presently held under a bituminous shale licence by Altius Minerals Corporation of Newfoundland. Altius recently drilled 14 holes on their licence, totalling about 4000 m of coring: nine holes were in the shales at Frederick Brook, two holes were at Rosevale, and three holes were near Dover (Fig. 92). The cores were sampled at 1.5 m intervals and the samples discharged for Rock-eval pyrolysis and Fischer assay.

The kerogen-rich rocks of the Frederick Brook Member feature a wide spectrum of physical and chemical characteristics that have led to various classifications or definitions of lithotypes (King 1963; Macauley and Ball 1982; Smith 1985; Smith and Gibling 1987; St. Peter 1992). Macauley and Ball (1982) subdivided the Frederick Brook Member at Frederick Brook into four informal zones on the basis of physical and chemical attributes of the shales there. They named the two most commercially significant zones the 'Dolomite Marlstone Zone' and the 'Albert Mines Zone.' The former zone occurs in the lower part of the Frederick Brook Member and is characterized by subfissile, laminated dolomitic and kerogen-bearing marlstone that yields about 50 L/t to 65 L/t of oil. The Albert Mines Zone occurs in the medial part of the member and comprises mostly microlaminated oil shale characterized by alternating paper-thin lamina of kerogen, carbonates (dolomite and calcite), and silicates (illitic clay and quartz and albite silt; Table 5). Shales of the Albert Mines Zone give oil yields in the range of 80 L/t to 100 L/t of rock (Macauley and Ball 1982).

Macauley and Ball (1982) used information from drillhole intersections, Fischer assays, and Rock-eval pyrolysis data from cores to calculate the in situ resource of oil shale in the two

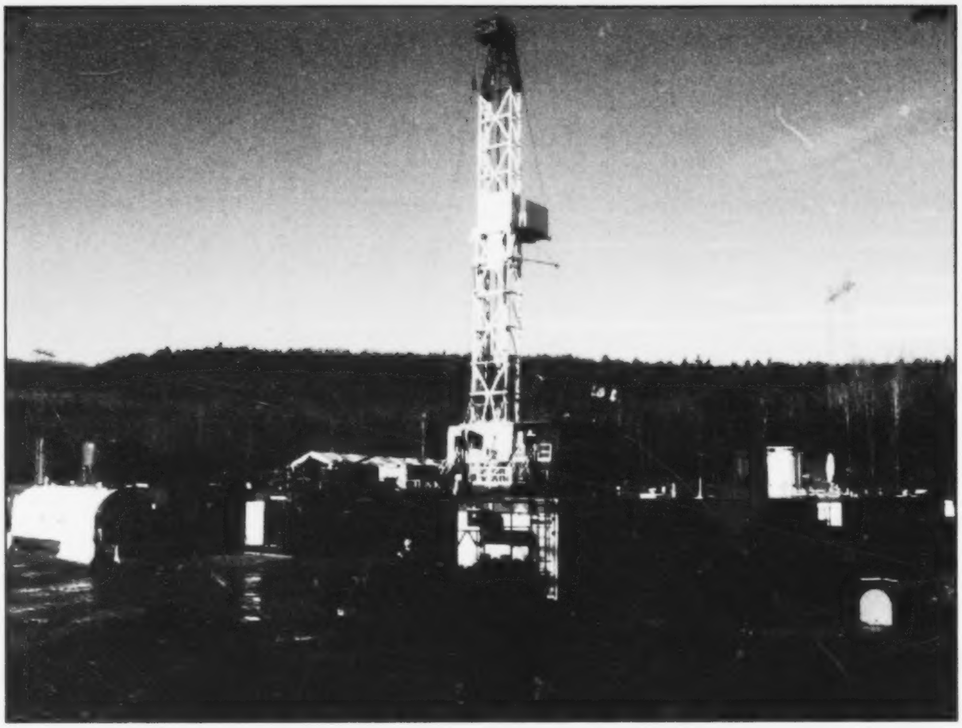

Figure 91. The F-88 (Well 711) of Corridor Resources Inc. at the McCully Field near Sussex.

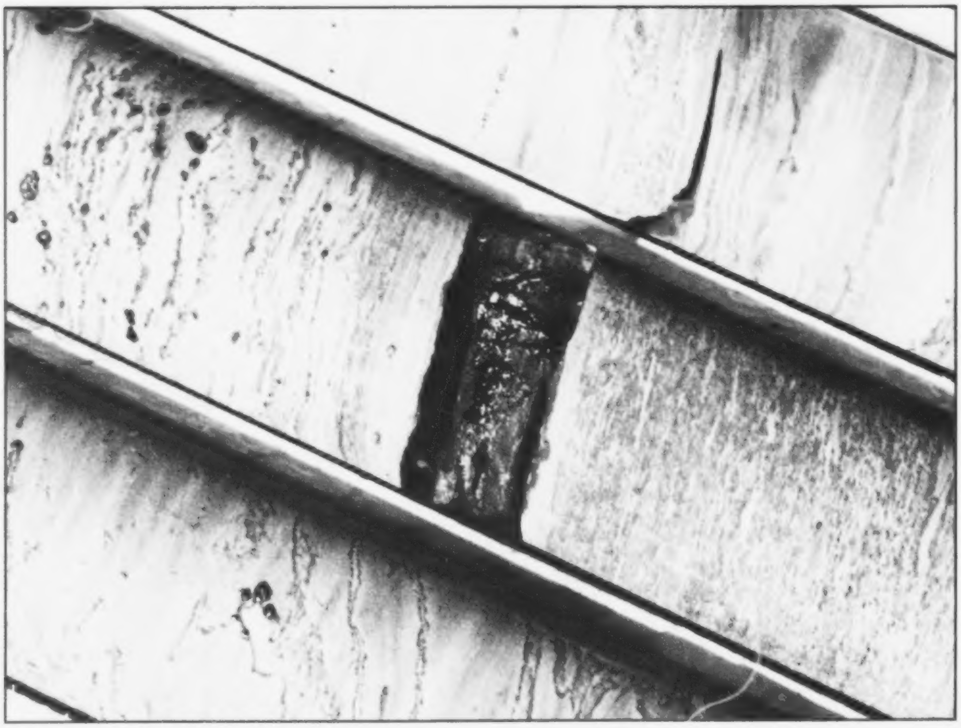

Figure 92. Oil seep in shale of the Frederick Brook Formation, cored by Altius Minerals Corporation.

significant zones at Frederick Brook. Their estimate was about 220 million barrels of shale oil in a volume of rock measuring 1200 m by 730 m on surface to a depth of 600 m. Additional resource would be available from leaner shales below and above the Albert Mines Zone. They offered no suggestion for a plausible mine plan or for the possible configuration of an open pit by which the shales could be excavated. Significant dilution would obviously occur from wallrock removal to achieve the estimated dimensions of an open pit dug to a depth of 600 m.

The scale of the oil shale resource in the eastern Moncton Subbasin is unknown. Several issues or constraints would need to be addressed if commercial viability is to be achieved. For example, the number of boreholes in the deeper part of the subbasin is insufficient to determine the regional thickness, organic content, and maturation level of the shales. The existing data from surface exposures and wells suggest that the prospective higher grade beds are restricted to an area from Rosevale to Frederick Brook (Albert Mines) and east to Taylor Village (Wright 1922; Alcock 1948a, 1948b; Timm et al. 1948; Macauley and Ball 1982). Another prospective area lies on the north limb of the Weldon Syncline between Stoney Creek and Saint-Joseph (Plate 4). Boreholes near Berryton, Steeves Mills, and Baltimore Station demonstrate that the Albert Formation and its constituent Frederick Brook Member change facies into coarse fluvial–alluvial rocks of the Steeves Mills Formation along the northwestern side of the subbasin (Fig. 13, 14), thereby excluding that area from consideration. Organic maturation data at Well 333 indicate that, in the deeper part of the subbasin (Fig. 14), the Frederick Brook shales are in the gas window and therefore too thermally degraded to yield much oil upon retorting (MacIntosh and St. Peter 2005).

The structural geology syntheses by Park and St. Peter (2005) and Park et al. (2007) are based on the exhumed beds at Rosevale, Frederick Brook, and Saint-Joseph. These syntheses demonstrate widespread layer-parallel early slip surfaces, implying structural repetitions. The oil shale beds also show synsedimentary slump folds and two phases of tectonic folding. The incompetency of the oil shale intervals relative to their bounding strata results in an inordinate amount of strain (shears and faults) from both extensional and compressional stresses being focused along the shale zones (Wright 1922, his Fig. 3; Macauley and Ball 1982; Brown and Whaley 1986, p. 38–39). The complexity of the resulting geometry of high-grade oil shale beds in any given area will likely necessitate much additional trenching, drilling, and careful structural analysis. Only when the geometry, thickness, grade, and maturation level of the oil shale beds are understood will it be possible to assess whether sufficient resource exists in a given area or within the subbasin as a whole to warrant commercial development.

Coal

Known coal occurrences in the report area occur mainly in the Late Carboniferous Cumberland and Pictou groups. Minor discontinuous coal lenses appear in the grey plant-bearing sandstones of the Boss Point Formation (Cumberland Group) (McMullen 1931, p. 49) but appear to have limited thickness and extent. Exceptions are laterally continuous coal seams in the Ward Point Member (Boss Point Formation) at Slacks Cove on the southern tip of Maringouin Peninsula. The coal seams there (see detailed log by Calder *in* Browne 1991) occur in a 2 m wide zone and consist of two 18 cm thick seams interbedded with massive grey mudstone. Narrow coal seams in the Boss Point Formation on Grindstone Island (Gesner 1840) are directly along strike and are likely a continuation of the Slacks Cove coals.

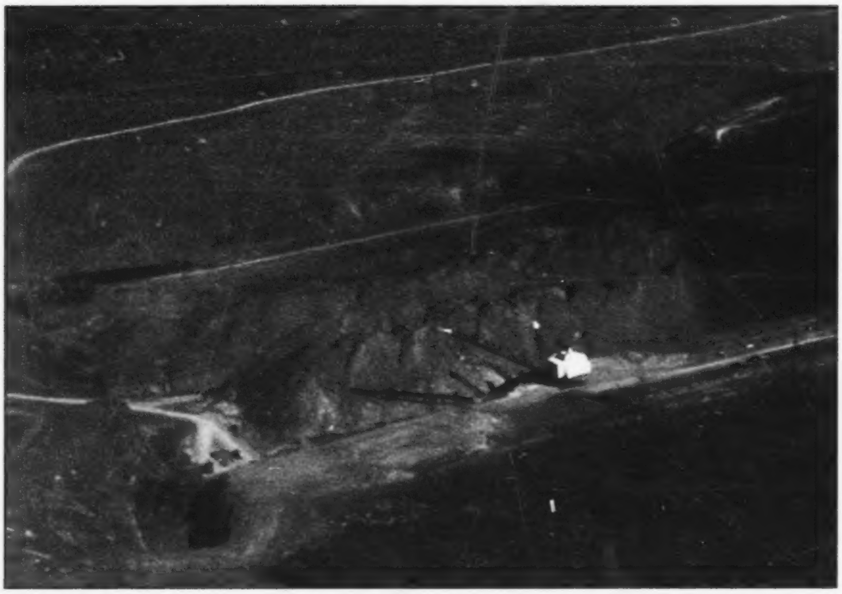

Figure 93. Dragline operation at the Minto coal field in the Grand Lake area, central New Brunswick.

The thickest coal seam in New Brunswick is found in the Minto Formation at the base of the Pictou Group on the New Brunswick Platform near Minto and Chipman (Fig. 6) and supports the province's only known economic coal reserves. The first coal shipment from this area purportedly left Grand Lake for Boston more than 350 years ago (Martin 2003, p. 23). The Minto coal seam is currently being mined by NB Coal Limited, a wholly owned subsidiary of NB Power (Fig. 93). In 2007 the company extracted approximately 150 000 t of coal from their Salmon Harbour open pit for use at NB Power's Grand Lake thermal generating station.

Due to difficulties with overburden geology, unmapped underground workings, and increasing depth to coal, NB Coal is currently relocating their mining operations from Salmon Harbour to Albrights Corner West. The Minto coal seam occurs in a sandstone-dominated sequence that is lithologically similar to and coeval with the South Bar Formation in Nova Scotia. That formation constitutes the lower part of the Morien Group in the Sydney Subbasin and hosts subeconomic coals (Rust et al. 1987).

Although time-equivalent to the Minto Formation, the Salisbury Formation contains only rare, thin coal seams (Stewart 1941b; Gussow 1953). The most numerous and widespread coal occurrences in southeastern New Brunswick appear in the overlying Richibucto Formation. Gesner (1842) and Ells (1883) noted thin (<10 cm) coal seams near Little Shemogue, Tedish River, and Dupuis Corner (Plate 2). Other thin (<20 cm), laterally continuous coal seams in the Richibucto Formation were traced at several localities on Gaspereau River near Port Elgin and in the Smith Cut Stone and Quarries Ltd. site on the east side of Scoudouc River in Shediac (Plates 2, 3). In the Beersville area about 80 km northeast of Minto, the Richibucto Formation hosts subeconomic coals (Ball et al. 1981; Hacquebard 1986).

Major economic deposits of coal occur in similarly aged rocks in Nova Scotia (Sydney Mines Formation in the upper Morien Group) and in late Westphalian strata offshore beneath the Gulf of St. Lawrence and Prince Edward Island (Hacquebard 1986; Grant and Moir 1992).

METAL RESOURCES

Carboniferous strata in the report area host a number of metallic mineral occurrences that can be broadly subdivided into 1) stratabound sediment-hosted types, and 2) fault-related vein types. An overview of the occurrences and some guides for exploration are given below. These occurrences are plotted on Plates 1 to 6 by name, commodity, and Unique Reference Number (URN). Additional information on each occurrence is available through the NBDNR Mineral Occurrence Database (NBDNR 2008).

Stratabound Sediment-Hosted Types

Stratabound sediment-hosted deposits in the report area are classified into four categories:

1. 'continental redbed-type' copper–silver ± lead–zinc deposits
2. sandstone-hosted uranium ± yttrium and phosphate deposits
3. paleoplacer deposits (including gold)
4. Mississippi Valley-type lead–zinc ± copper–manganese deposits.

The base-metal and uranium occurrences are commonly associated with local or basin-scale redox boundaries and tend to be associated with specific stratigraphic intervals in the sedimentary pile. They are the most abundant type in the area and thus form the main focus of this section. Paleoplacer gold occurrences and Mississippi Valley-type lead–zinc make up a small but potentially significant percentage of the metallic mineral resources in Carboniferous rocks.

Continental Redbed Type

Continental redbed-type copper deposits are significant contributors to world copper reserves. Such deposits are typically hosted by anoxic sediments in continental sedimentary basins containing thick sequences of redbeds and evaporites that were deposited in arid to semiarid environments (Kirkham 1989). Hydrocarbons are thought to play an important role in the formation of some of these deposits — in particular, the large deposits in the Dzhezkazgan district of the former USSR (Kirkham 1989). The sulphides in such deposits are typically zoned with a copper-rich zone underlying a lead–zinc-rich zone (Kirkham 1989). The metals are derived from the detrital component of the redbeds and are transported by oxidizing, chlorine-rich brines produced by the dissolution of evaporites and/or saline formational waters. In the traditional model for the formation of these deposits, metals are precipitated at a redox front when metalliferous brines encounter fluvial sediments containing abundant carbonized plant material or diagenetic pyrite that acts as reductants (Kirkham 1989; Lines et al. 1996; McLeod 1997). A variation on this model involves both mobile metalliferous brines and mobile reductants such as hydrogen sulphide; the latter is produced by bacterial reduction of sulphate contained in hydrocarbons underlying the redbeds (Kirkham 1989) and has the potential to produce very large deposits.

The Carboniferous sedimentary basins of southern New Brunswick feature all of the above-cited necessary components and thus provide an ideal geological environment for the formation of continental redbed-type copper–silver deposits. An additional factor to consider in the area is the spatial association of sediment-hosted base-metal sulphide occurrences with major basin-bounding faults (McLeod 1997). The Shepody (Mabou Group), Boss Point and Grande Anse (Cumberland Group), and Richibucto (Pictou Group) formations contain more than 30 major and minor redbed-type occurrences in the report area. The most significant occurrences known to date lie at or near the base of the Shepody and Boss Point formations.

Shepody Formation: Copper mineralization is widespread in the lowermost grey sandstone beds of the Shepody Formation, a formation that occurs only in the Cumberland Subbasin. The mineralization typically appears in the first grey sandstone or intraformational conglomerate bed immediately above red, fine-grained sandstone or siltstone of the Maringouin Formation. Nearly all exposures of this Maringouin–Shepody contact viewed by the authors contain some copper mineralization, commonly in the form of malachite after chalcocite. The New Horton deposit (Plate 6) is in part structurally controlled; it occurs in quartz–carbonate-cemented breccias in sandstone in the Lockhart Lake Fault zone (St. Peter 1996d). Other basal Shepody occurrences such as those at Midway, Midway South, Inner Head, Cape Maringouin (Plate 6), and Pecks Point (Plate 5) show no obvious relationship to structure. Both the Midway and New Horton deposits contain chiefly chalcocite and malachite replacing carbonized plant debris.

Gulf Minerals conducted the most recent work on these deposits in the late 1970s. Gulf geologists concluded there was potential for a large-tonnage, low-grade copper deposit and recommended drilling to test the downdip extension of the mineralization at Midway. However, no further work was done (Boyd 1978). On the basis of three drillholes spaced over a distance of 480 m, the copper content of the 3.3 m thick basal sandstone was estimated to be 0.40% Cu (Wright 1951). Samples of mineralized sandstone were taken from the base of the Shepody Formation at Cape Maringouin and along strike at Pecks Point during the present study. Analyses of those samples indicate potential for high-grade copper (>2.00% Cu) and silver (>50.00 g/t Ag) at this stratigraphic horizon. Base metals were also observed in grey channel sandstone in the upper part of the Shepody Formation at Pecks Point. Mineralization at this locality is mainly chalcocite and pyrite, which occur as lenses and nodules in reduced channel lags at a redox boundary slightly discordant to stratigraphy. The host rocks are heavily stained with limonite and contain abundant carbonized plant trash coated with malachite. A grab sample of the mineralized sandstone there yielded greater than 2.00% Cu and greater than 50.00 g/t Ag. The lateral extent and downdip extension of the mineralization at the base of the Shepody Formation is essentially untested.

Boss Point Formation: The most significant redbed copper occurrences in the Boss Point Formation are located near the base of the formation in the southeastern Moncton Subbasin and the Sackville Subbasin. In these areas, the Shepody Formation is absent due to facies changes in the Mabou Group (see ***Mabou Group*** in Chapter 2), and the group itself is composed almost entirely of coarse-grained redbeds of the Hopewell Cape Formation. The potential for the Boss Point Formation to host laterally extensive stratiform copper horizons therefore appears to vary, depending on the stratigraphy of the underlying Mabou Group or, more specifically, whether the Shepody Formation is present below. This apparent relationship may simply be coincidental. However, it could also be explained thusly: where the Shepody Formation is absent, the Boss Point Formation is the first major reduced horizon that would be encountered by ascending metal-rich fluids. Moreover, the permeable oxidized sediments of the Hopewell Cape Formation are excellent aquifers through which ore fluids could pass and are also potential sources of metals. The lack of mineralization at the base of the Boss Point Formation on Maringouin Peninsula in the Cumberland Subbasin — an area where rocks of the Shepody Formation are widely preserved — seems to support this premise.

The largest known stratabound copper deposit in New Brunswick is the former Dorchester copper mine (Plate 5), which occurs in basal sandstones of the Boss Point Formation. The mineralized sandstones are underlain by the Hopewell Cape Formation along the northern margin of the Sackville Subbasin. The deposit was mined intermittently during the late 1800s and early 1900s (Martin 2003, p. 157–160) and experienced limited, sporadic exploration from the 1950s to 1970s. In 1992 the deposit was investigated for the possibility of extracting copper by bioleaching (Brown 1992). It was recently explored by Cornerstone Resources Inc., but the results of their work remain confidential. The northeast-trending, lenticular deposit at Dorchester has possible reserves of 2.3 Mt grading 2% Cu (Kirkham 1989). The main copper-bearing mineral is chalcocite; it occurs mainly as a replacement of plant fragments but also appears where no evidence exists of organic detritus (McLeod and Ruitenberg 1978).

Other notable base-metal sulphide occurrences at the base of the Boss Point Formation are located at Demoiselle Creek and Curryville in the Hillsborough area. There, the Boss Point Formation is underlain by coarse-grained redbeds of the Hopewell Cape Formation, similar to the stratigraphic setting at the Dorchester copper deposit. Unlike the Dorchester mine, the Demoiselle–Curryville showings lack abundant plant detritus and have pyrite as the main reductant (McLeod 1997). The Demoiselle Creek occurrence was drilled by Noranda Exploration Ltd. in the early 1990s (Woods 1993) and most recently was explored by Mindset Resources Limited. Disseminated base-metal sulphides and chalcocite–specularite nodules are the main types of mineralization at Demoiselle Creek (Woods 1993; McLeod 1997). The deposit is vertically zoned, from copper-rich at the base to lead–zinc-rich at the top. The north-trending Demoiselle Creek Fault and related structures are believed to play a vital role in concentrating the mineralization at Demoiselle Creek (McLeod 1997). Up to 40 m (vertical extent) of flat-lying sandstone is mineralized in the hanging wall of the fault over a strike length of 250 m. A 9.2 m section in diamond-drill hole DEM-1 graded 0.77% Cu, 0.08% Pb–Zn, and 7.3 g/t Ag (Woods 1993).

Minor base-metal sulphide mineralization associated with plant detritus is found in basal Boss Point strata at Dorchester Cape (Plate 4). The mineralization at this contact may be negligible because of the unique lithology of the underlying Hopewell Cape Formation. Extensive calcrete–silcrete beds in the Dorchester Cape Member (see ***Dorchester Cape Member*** in Chapter 2) cap the Hopewell Cape Formation in the area, possibly preventing metal-rich fluids from reaching the overlying grey beds of the Boss Point Formation.

Some base-metal occurrences in the Boss Point Formation are enriched in lead–zinc relative to copper, including a showing discovered in 1994 by Noranda Exploration Ltd. on Joe Brook north of Sackville (Plate 5). The stratigraphic position of this showing lies near the contact with the overlying Pictou Group (Plate 5). The mineralization consists of very fine-grained disseminated galena and sphalerite associated with coal fragments in grey sandstone to siltstone, and minor malachite on mudstone intraclasts within conglomerate (Woods 1994).

The possibility of a copper zone underlying the lead–zinc mineralization at surface is indicated by the zoned distribution of sulphides at Demoiselle Creek and other sedimentary copper deposits (Woods 1994). The likelihood is enhanced by the proximity of Joe Brook to the highly cupriferous bogs at Tantramar that contain up to 5.6 % Cu and up to 2.3 g/t Au in the peat (Boyle 1977). The Dorchester Fault lies immediately north of the bogs and is interpreted to have provided a conduit for metal-rich groundwater (Rose and Johnson 1990). Results of a 1995 drilling program conducted at the Joe Brook claims by Noranda were disappointing (Deering 1996), but the drillholes did not penetrate the Boss Point Formation.

Other, presumably localized, occurrences of fairly high-grade zinc were discovered northwest of Sackville during the current mapping program. Two localities near Breau Creek (Plate 5) contained lead and zinc sulphides (up to 1.28% Zn) as well as pyrite–marcasite nodules within masses of coalified fossil logs in channel lag conglomerates of the Boss Point Formation. Mineralization on Breau Creek lies adjacent to the Dorchester Fault, supporting the chiefly structural model proposed by McLeod (1997) for these types of occurrences.

Grande Anse Formation: Minor base-metal occurrences in the Grande Anse Formation are related to local concentrations of diagenetic pyrite and plant material within reduced beds of sandstone in otherwise redbed sequences. The mineralization does not appear to be associated with any specific stratigraphic horizon. Ryan and Boehner (1994) propose a solution-front model for copper occurrences in the Cumberland Subbasin in Nova Scotia. In this model, metals are derived from red overbank facies and precipitated in laterally adjacent channel sandstones where sufficient quantities of plant trash or pyrite are present. A similar mechanism seems likely for these types of occurrences in New Brunswick.

Richibucto Formation: As with the Grande Anse Formation, base-metal mineralization hosted by the Richibucto Formation (Pictou Group) tends to be randomly distributed and of limited lateral extent. Base metals are typically associated with abundant coalified plant material in channel lags at the base of grey sandstone sequences. The most significant and well-studied example of this type is the Coburg Road occurrence near the Gaspereau River about 9 km northwest of Port Elgin (Plate 2). Lines (1996) determined that the copper minerals there, which occur within medium- to fine-grained grey sandstone containing coalified plant material, are covellite, chalcocite, chalcopyrite, bornite, cuprite, and malachite. The copper mineralization replaces the cell structure of fossil plant material and pre-existing sulphides such as pyrite and sphalerite. Four out of seven grab samples from a shallowly dug pit on the north side of the road yielded more than 900 ppm Cu, with a high reading of 1450 ppm Cu. Lines (1996) suggested several possible sources for the metalliferous fluids: the adjacent overbank facies, the underlying igneous basement rocks of the Westmorland Uplift, or a deeply buried redbed or evaporite source. In the last two scenarios, the fluids would have been transported along a buried fault or fracture system.

Sandstone-Hosted Uranium

Sandstone-hosted uranium occurrences are found in a variety of fluvial, lacustrine, and alluvial rocks in the Maritimes Basin in New Brunswick. The majority of such occurrences in southern New Brunswick were discovered in the 1970s and early 1980s during a Canada-wide uranium exploration boom. Rising uranium prices triggered the recent (2008) uranium exploration bonanza that produced the biggest staking rush in the province since massive sulphides were discovered near Bathurst in the early 1950s (McLeod and Johnson 2007).

Sediment-hosted uranium occurrences in the Maritimes Basin of southeastern New Brunswick have not been thoroughly studied. Hassan et al. (1987) suggest they are analogous to the 'roll-front' sandstone uranium deposits of the western United States. Roll-front uranium deposits are a subtype of sandstone-hosted deposits (Finch 1996), in which the uranium is transported in oxidized form by groundwater and deposited at reduction fronts, with the reductants typically being carbonaceous matter, sulphides, or methane (Eckstrand 1984). Finch (1996) suggests that the uranium ores in some sandstone uranium deposits were most likely precipitated by reduction between uranium-bearing groundwater and underlying saline brine. The source of the uranium in these deposits is varied. In New Brunswick, most models contend that buried Devonian uraniferous granitoid intrusions and/or related volcanic rocks are involved either directly (Hassan et al. 1987), or indirectly, through recycling of basement clasts or uraniferous ash in finer grained sedimentary rocks (McLeod and Johnson 2007).

The uranium occurrences in the report area appear at different stratigraphic levels in a variety of host rocks. Some showings lie in close proximity to faults, known to provide channelways for the uranium-bearing fluids or introduced reductants (Eckstrand 1984). The most significant occurrences are in the Horton and Sussex groups north of Moncton (Fig. 10; Plate 3). This cluster of uranium occurrences appears to be associated with northeast-trending faults transecting the Indian Mountain Deformed Zone and also with the unconformity at the base of the Sussex Group. At the Lutes Mountain uranium occurrence near The Gorge, the uranium mineralization occurs in the form of pitchblende nodules and pitchblende coatings on clasts, as well as in fractures in conglomerate and sandstone of the Stilesville Formation near the unconformity with early Paleozoic instrusive rocks. The original boulder discovered by BP Minerals Ltd. contains 0.3% U_3O_8, 1.00% Cu and elevated (0.10%) Y (Rose and Johnson 1990). Northeast of The Gorge, uranium showings at McQuade Brook and Scotch Settlement are associated with phosphate-rich beds in the Albert Formation on the north side of the North River Fault (Fig. 10).

Fluvial sandstones in the Pictou Group also contain several minor uranium occurrences, commonly associated with plant matter or diagenetic pyrite nodules. Although the mineralization tends to be sporadic, it can be fairly high grade and has the potential to be laterally extensive (Dunsmore 1977). Occurrences of this type in the Cape Tormentine and Sackville areas were investigated by Brunswick Mining and Smelting Ltd. in the early 1980s, but drilling failed to discover significant amounts of uranium mineralization.

Paleoplacer Deposits

Paleoplacer occurrences exist at two stratigraphic intervals in the report area. A paleoplacer titanium–iron horizon appears in conglomerates of the Hopewell Cape Formation near Taylor Village (Plate 4), and paleoplacer gold was discovered in Boss Point sandstone float near the Tantramar copper bogs in the north-central part of Plate 5 (Rose and Johnson 1990). The conglomerate horizon at Taylor Village is fairly flat-lying and consists of red, calcareous pebble conglomerate containing detrital grains and pebbles of ilmenite 2 mm to 24 mm in size. The paleoplacer was determined to be economically unviable (Hudgins 1999). The likely source for the massive ilmenite pebbles is the now-buried Lower Coverdale titanium–iron deposit located approximately 15 km to the northwest near Moncton. The deposit occurs in an anorthosite complex of probable Devonian age (Barr et al. 2007) that is capped by a saprolitic-weathering horizon and less than 150 m of sandstone of the Boss Point Formation. Noranda reports grades from the deposit of approximately 11.6% TiO_2 over a width of 128 m (Woods 1995). The existence of this paleoplacer is further proof that the Westmorland Uplift was a highland source shedding detritus into the Hopewell Cape Formation.

In the late 1990s paleoplacer gold was discovered in angular sandstone float of the Boss Point Formation in the cupriferous bogs west of Tantramar River (McLeod 1997). Crushed rejects from a sample yielding 11.5 g/t Au were examined by McLeod (1997) and found to contain native gold within minute veinlets in recrystallized vein quartz, interpreted to be detrital grains. Anomalous gold in the bog area was first known in the 1960s when Dome Exploration (Canada) Ltd. drilled beneath the bog. They reported an assay of 6.9 g/t Au over 1.4 m, within grey shale of the Boss Point Formation at a depth of about 25 m (Dome Exploration (Canada) Ltd. 1964). Analyses of the bog muck also returned anomalous values of up to 2.3 g/t Au (Boyle 1977).

The presence of paleoplacer gold in float in this area is intriguing in light of the discovery of a paleoplacer pyrite horizon in similar sandstone north of the bogs (Johnson and McLeod 1998). The horizon occurs in the Boss Point Formation where it overlies the Westmorland Uplift on Memramcook River. The horizon seems to end abruptly to the west near Petitcodiac River and to the south in the vicinity of the Dorchester Fault. Interpretation of induced polarization survey results by Canerpa Ltd. suggests that the gold-bearing horizon intersected in the Dome drillhole was also north of the Dorchester Fault (Holt 1973). The spatial association of the paleoplacer horizon with the Westmorland Uplift is probably not coincidental. The chief guide to exploring for paleoplacer deposits is to recognize paleotopographic features that produce abrupt changes in gradient and in stream flowage such as valley heads, fault scarps, and basin margins (Eckstrand 1984). Gold values obtained to date from the pyrite-bearing sandstone are low (<1–6 ppb Au), but this horizon warrants further investigation.

Mississippi Valley Type

Mississippi Valley-type lead–zinc deposits occur in platformal carbonate successions such as the Windsor Group in New Brunswick and Nova Scotia. The most common distribution of the ore minerals (sphalerite and galena) is as open-space filling in brecciated dolomitic limestone or less commonly in evaporites and clastic rocks (Eckstrand 1984). Pre-Carboniferous basement highs underlying the carbonates are a feature commonly associated with this deposit type (Patterson 1993).

About 3 km southwest of Albert Mines (Plate 4), a deposit of this type occurs where the Windsor Group lies unconformably on basement rocks of the Caledonia Uplift (McLeod 1980). Galena, sphalerite, chalcopyrite, and pyrolusite occupy open spaces in vuggy stromatolitic limestone of the Gays River Formation that unconformably overlies mafic volcanic rocks and granitic intrusions of the Neoproterozoic Broad River Group (Rose and Johnson 1990). A pyrolusite-rich layer in the limestone yielded 0.26% Pb, 0.25% Cu, and 0.20% Zn. At a similar occurrence near Berryton (Plate 4), the mineralization occupies zones of solution collapse in limestone of the Gays River Formation (Rose and Johnson 1990).

Fault-Related Mineralization

The stratigraphic settings of fault-related occurrences in the report area are more highly varied than for the stratabound types. Fault-related mineralization in the area includes:

- barite–celestite ± manganese ± base-metal sulphides associated with the Dorchester and Memramcook East faults at Memramcook East, Upper Dorchester, and Woodhurst, and
- base-metal ± barite occurrences related to unnamed faults at Johnson Mills and Lower Rockport on Maringouin Peninsula.

At Memramcook East (Plate 3) quartz–barite veins containing minor chalcopyrite, galena, tetrahedrite, fluorite, anglesite, and witherite have been recognized since the mid-1800s (Rose and Johnson 1990). Along the Memramcook East Fault, barite intergrown with quartz occurs in lenses and replaces brecciated siltstone and sandstone of the Memramcook Formation. The vein zone is up to 30 m wide and can be traced along strike for about 250 m (Rose and Johnson 1990). Interest in the base-metal potential of this property has been sporadic since the early 1960s. McIntyre Porcupine in 1961 and Cuvier Mines Inc. in 1983 conducted the most comprehensive work.

Massive barite–celestite zones hosted by vuggy, siliciclastic and algal limestone and siltstone of the Lime-kiln Brook Formation (Windsor Group) are associated with the Dorchester Fault at Upper Dorchester (Plate 4). Celestite replaces limestone fragmented by faulting and solution collapse, and a second generation of celestite and barite fills voids within breccia (Rose and Johnson 1990). The mineralized zone is 4 m to 15 m wide and has associated veins and vugs filled with calcite, albertite, and semisolid bitumen. Along strike to the northeast near Woodhurst (Plate 5), manganese appears in vugs within barite veins associated with the Dorchester Fault. The host rocks are sandstone and conglomerate of the Hopewell Cape Formation.

Elevated copper (up to 500 ppm) is associated with barite veinlets in sheared maroon sandstone and siltstone of the Chignecto Bay Member (Boss Point Formation) near Johnson Mills (Plate 4). The shear zone and mineralization are likely related to the Shepody–Beckwith Fault zone that lies about 1.5 km to the north, or to the cryptic Lockhart Lake Fault, which may define the surface trace of the Lime-kiln Brook–Maringouin formational boundary 1 km to the south (see ***Lockhart Lake Fault*** in Chapter 3).

On the shore at Lower Rockport (Plate 6), disseminated pyrite, sphalerite, and galena occur in brecciated sandstone of the Boss Point Formation. Mineralization is located in a northwest-trending, 20 cm wide breccia zone parallel to prominent fractures in the sandstone. Zinc values are up to 5600 ppm. No major fault zones are known in the vicinity.

INDUSTRIAL MINERALS

Gypsum

Gypsum was a major export commodity to eastern Canada and the United States from the 1820s to the 1970s (Webb 2002a, 2002b; Martin 2003). It was removed from quarries and, to a lesser extent, from underground mines in the Upperton Formation south of Hillsborough in the Gray Brook and Wilson Brook areas (Plate 4). The Albert Manufacturing Company mill constructed at Hillsborough in 1861 was, at the time, the largest gypsum manufacturing plant in North America (Hamilton and Barnett 1970). Throughout the long history of production, most of the export was crude unprocessed gypsum, ground gypsum, land plaster, and hardwall plaster. Markets were established in the United States, Australia, New Zealand, South Africa, West Indies, and Japan (Webb 2002a). Production varied widely over the years and depended mainly on the level of import duties capriciously levied by the United States to protect its domestic producers (Webb 2002a). Between 1950 and 1970 production averaged about 100 000 t per year (Hamilton and Barnett 1970). The business history of gypsum mining in the Gray Brook and Wilson Brook areas, the names of the various quarries, their locations, and when they were active is detailed in Webb (2002a, 2002b).

Following the closure of the quarries and decommissioning of the Hillsborough processing and wallboard plant in 1980, exploration for new reserves took place via the review of historical mining and exploration records, bulk sampling, and drilling and assaying of new shallow coreholes adjacent to the former workings at Gray Brook and Wilson Brook (Whaley 1988a, 1988b, 1990a, 1990b, 1994, 1995, 1997, 1998a, 1998b; Webb 2002a, 2002b). The assessments demonstrate that unexploited gypsum resources still exist in the area and could possibly support a future commercial venture.

Gypsum on Maringouin Peninsula was first referred to by Logan (1843). From 1906 to 1920 a few thousand tons were quarried by the New Brunswick Gypsum Company Ltd. (a subsidiary of the Albert Manufacturing Company) and shipped as crude gypsum to American plaster mills (Webb 2002c). The Maringouin operation ceased in 1920, apparently because the main processing mill in New Haven, Connecticut, was destroyed by fire. Webb (2002c) undertook an assessment of gypsum of the Lime-kiln Brook Formation on the eastern shore of Shepody Bay and on the margin of a waterfilled sinkhole ('Pink Rock Lake') that lies about 500 m east of Shepody Bay (Plate 4). He described two areas of fairly elevated topography near Pink Rock Lake that merit further attention.

Rock Salt

Rock salt has been known for decades in the Maritimes Basin of southeastern New Brunswick. The first indication of subsurface rock salt came in 1921 when the D'Arcy Exploration Company cut 147 m of evaporites in its oil and gas exploration borehole, Well 320, near Boyd Creek (Plate 4). Hamilton (1961a) summarizes the geology and analytical data from wells drilled in the salt before 1961. At that time, six gas and oil exploration wells had encountered rock salt near Weldon and Gautreau Village on the west and east sides of Petitcodiac River, respectively. In 1961 Sifto Salt Ltd. drilled four additional boreholes in the Weldon area to assess the glauberite potential of the Gautreau evaporites (Webb 1977).

The rock salt and associated glauberite at Gautreau Village and Weldon are assigned to the Gautreau Formation as originally defined by Norman (1932). Chapter 2 provides geological details of the Gautreau Formation, and St. Peter (1992, p. 56–63) describes the mineralogy, paragenesis, and depositional environment of the rock salt and glauberite in the upper part of the formation. Hamilton (1961a) estimates an in-place salt resource of greater than 1 Bt.

Webb (1977) cites a glauberite resource of 25 Mt with an average grade of 23% Na_2SO_4 in the Gautreau Village–Weldon deposit.

In 1949 Shell Oil Company cut very clean rock salt of the Pugwash Mine Formation (Windsor Group) in Well 325 from 543 m to 1520 m. That intersection revealed the source of the previously identified large negative gravity anomaly in the northwest 'corner' of the Sackville Subbasin near Dorchester (Gussow 1953, his Fig. 11 (section U–V) and his Fig. 13). Imperial Oil Limited delineated the regional scale of the rock salt body further when they drilled Well 330 just south of Well 325 in 1960 (Fig. 32, 71; Plate 4). Although the rock salt in Well 330 is less clean than in Well 325 (containing several intervals of shale, anhydrite, and limestone), it appears in very thick intervals over a drill thickness of 780 m (Fig. 33). Well 716, 7 km northeast of Well 325, cut rock salt in depth interval 1956 m to 2111 m, demonstrating a considerable reduction in salt thickness and a much deeper section than in Well 325. The salt intersections in Wells 325, 330, and 716, combined with the triangular surface area defined by those wells, indicate a roughly estimated, in-place salt resource of 10 Bt. Obviously much additional resource in the Dorchester salt body lies outside the perimeter of that triangular area.

As noted earlier under ***Pugwash Mine Formation*** in Chapter 2 and under ***Wood Creek Fault*** and ***Tantramar Fault*** in Chapter 3, convincing geological, seismic reflection, and gravity data suggest that significant buried salt bodies of the Pugwash Mine Formation exist in the Sackville Subbasin (Martel 1987). In particular, a northeast-trending salt body almost certainly lies beneath Fort Cumberland Ridge and approximately follows the surface trace of the Tantramar Fault (Plate 5). A northwest–southeast seismic profile (line 29Y of the 1984 Chevron–Irving program) in the Upper Point de Bute area images a large seismically transparent (salt?) body that rises to within 800 m of surface. No holes have been drilled in that area to validate the interpretation, but the data suggest a large salt body within exploitable depth.

Limestone

In 2001 Brunswick Limestone Ltd. opened the first limestone quarry in southeastern New Brunswick in the Macumber Formation immediately west of Edgetts Landing (Fig. 3; Plate 4). The company specializes in randomly shaped and custom square-cut flagstone, split and bed-sawn building stone, random wall stone, and stepping stone. The limestone is sold in two colours: antique red (a variegated mix of dark red and greyish green stone), and antique green (a greyish green stone with tints of yellow and black). The company operates the quarry year-round and markets its products throughout eastern Canada and parts of the United States.

Sandstone

One of the earliest instances of sandstone being quarried for building stone in New Brunswick was during the construction of Fort Beauséjour near Aulac (Fig. 3; Plate 5). A 1761 report by British engineer Robert Bruce includes a map that shows a quarry situated about 800 m northeast of the fort (Martin 1990, p. 19). That description places the quarry in the Boss Point Formation.

Martin (1990) describes the period from 1850 to World War I as the Golden Age of Sandstone in New Brunswick. Albert and Westmorland counties in the southeastern part of the province supported about 20 active quarries during this period (Martin 1990, her Fig. 5). Of those quarries, 12 were in red, tan, or brown sandstones of the Boss Point Formation, six were in grey, brown, or red sandstones of the Richibucto Formation, and two were in red sandstones of the Salisbury Formation. Red stone was used almost exclusively as dimension stone, whereas the grey or brown stone was also employed as pulpstone, grindstone, and whetstone. Grindstone production from the Boss Point Formation at quarries on the island at the mouth of Shepody Bay was so prolific that it gave the isle its name – Grindstone (Plate 6). In addition to the larger historical quarries in Albert and Westmorland counties, several smaller disused pits, mainly in red sandstone, were located and described in an assessment of red sandstone resources in southeastern New Brunswick by Geosleuths Exploration Services (1995). The Geosleuths report notes quarries with remaining resource potential and provides guidelines for future red sandstone exploration.

During the latter half of the 1800s and early 1900s, New Brunswick sandstone of many colours was exported widely to the eastern United States and to eastern and central Canadian provinces. The dimension stone was used mainly to construct churches and government buildings, many of which still stand. A detailed historical description of the sandstone quarries in Albert and Westmorland counties is offered in Martin (1990, p. 41–63).

The only currently active sandstone quarry of note in the report area is a small excavation west of Sackville near Frosty Hollow (Plate 5). The quarry is located in the Salisbury Formation and is operated on a part-time, seasonal basis by Smith Cut Stone and Quarries Ltd. of Shediac. The company is the sole commercial supplier of red sandstone in New Brunswick. It provides ashlar in various sizes, shapes, and finishes as well as custom-carved stone and landscape stone.

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APPENDIX 1: LIST OF WELLS CITED IN TEXT

The Borehole Database of the New Brunswick Department of Natural Resources (NBDNR 2004) lists most wells in the province that were drilled for oil and natural gas, oil shales, coal, and uranium as well as for salt, potash, and selected other industrial minerals. It also lists some wells drilled for stratigraphic tests. Wells contained in the database have been drilled in the Carboniferous or Mesozoic basins. They are either deep test holes or provide significant stratigraphic information.

Abbreviations Used

UI	Unique Identification number: borehole number in NBDNR Borehole Database
DDH	Diamond-drill hole not in Borehole Database

Chevron	Chevron Canada Resources Ltd.
Columbia	Columbia Natural Resources Canada Limited
Imperial	Imperial Oil Limited
Irving	Irving Oil Limited
MariCo	MariCo Oil and Gas Corporation
NBGO	New Brunswick Gas and Oilfields Ltd.
NBO	New Brunswick Oilfields Ltd.
Noranda	Noranda Exploration Company Limited
PNB	Province of New Brunswick

UI No.	Company Well Name (in NBDNR Borehole Database)	Plate No.	Approximate Geographic Location
003	PNB Carboniferous Drilling Project 210	1	At Upper Cape
043	PNB Plumweseep No. 1	–	5 km northeast of Sussex (NTS 21 H/11) outside the report area; is the exploration hole that intersected the potash deposit currently being mined by PCS New Brunswick Division.
146	Irving–Chevron Middlesex No. 1	4	1.5 km west of Colpitts Settlement (western border of Plate 4)
172	Maritime Oilfields Ltd. West Stoney Creek No. 27	4	At Baltimore Station
190	NBGO Stoney Creek No. 47	4	2 km northeast of Stoney Creek Station
198	NBGO Dover No. 57	4	1 km north of Gautreau Village
200	NBGO Turtle Creek No. 59	4	At Rosevale

UI No.	Company Well Name (in NBDNR Borehole Database)	Plate No.	Approximate Geographic Location
226	NBGO Gautreau No. 85	4	0.5 km south of Gautreau Village
229	NBGO Gautreau No. 88	4	At Boyd Creek 1 km southeast of Gautreau Village
239	NBGO West Stoney Creek No. 100	4	2 km north of Baltimore Station
243	NBGO Stoney Creek No. 104	4	Near Hiram Brook, south side of Stoney Creek Field
247	NBGO Weldon No. 108	4	At Weldon
251	NBGO Weldon No. 112	4	1 km east of Weldon
254	NBGO Stoney Creek No. 115	4	3.5 km northeast of Baltimore Station
256	NBGO Stoney Creek No. 117	4	1.5 km northwest of Weldon
266	NBGO Baltimore No. 127	4	At Baltimore
290	NBO Shenstone No. 151	4	1.5 km southwest of Isaiah Corner
305	NBO Stoney Creek No. 166	4	1 km north of Dawson Settlement
317	NBO West Stoney Creek No. 71-1	4	1 km northwest of Dawson Settlement
318	NBO Surrey No. 1	4	At Surrey 2 km southeast of Hillsborough
319	NBGO Turtle Creek No. 1	4	3 km west of Village of Turtle Creek
320	D'Arcy Exploration Gautreau No. 1	4	At Boyd Creek, 1 km southeast of Gautreau Village
325	Shell Oil Company–NBO Dorchester No. 1	4	2 km northwest of Dorchester
326	Imperial–NBO Hillsborough No. 1	4	1.5 km southwest of Hillsborough
328	Imperial–NBO Berryton No. 1	4	0.5 km north of Berryton
330	Imperial–Dorchester No. 1	4	1.8 km south of Dorchester
331	Irving–Chevron Stoney Creek No. 1	4	Near Hiram Brook, south side of Stoney Creek Field
332	Irving–Chevron East Stoney Creek No. 1	4	2 km northwest of Weldon
333	Irving–Chevron Hillsborough No. 1	4	5 km southwest of Hillsborough
334	Irving–Chevron Little River No. 1	4	3.5 km east of the community of Little River
337	Atlantic Richfield Company, Boudreau No. 1	4	2 km northeast of Boudreau Village
339	Atlantic Richfield Company, Dover 1A	4	1 km north of Gautreau Village
340	Atlantic Richfield Company, Rosevale No. 1	4	At Rosevale
350	Canadian Occidental Petroleum Albert Mines 81-8	4	Near Frederick Brook, 1.5 km northwest of Albert Mines
353	Canadian Occidental Rosevale No. 1	4	3.5 km northeast of Rosevale
355	Petro-Canada Dover No. 1	4	2 km north of Gautreau Village
356	Petro-Canada Dover No. 2	4	1.5 km northeast of Gautreau Village

UI No.	Company Well Name (in NBDNR Borehole Database)	Plate No.	Approximate Geographic Location
364	PNB Weldon 49-1	4	1 km east of Weldon, 15 m from Well 251
366	Sifto Salt Ltd. Weldon 3	4	At Weldon
369	Canadian Merrill Upper Dorchester 1	4	1 km south of Upper Dorchester
370	Canadian Merrill Upper Dorchester 2	4	1 km south of Upper Dorchester
371	Canadian Merrill Upper Dorchester 3	4	1 km south of Upper Dorchester
372	Canadian Merrill Upper Dorchester 4	4	1 km south of Upper Dorchester
373	Canadian Merrill Upper Dorchester 5	4	1 km south of Upper Dorchester
374	Canadian Merrill Upper Dorchester 6	4	1 km south of Upper Dorchester
375	Canadian Merrill Upper Dorchester 7	4	1 km south of Upper Dorchester
376	Canadian Merrill Upper Dorchester 8	4	1 km south of Upper Dorchester
386	PNB Carboniferous Drilling Project 252	5	5 km northwest of Sackville
397	PNB Carboniferous Drilling Project 214	2	16 km south of Barachois
398	D'Arcy Exploration Company Cape Bald No. 1	2	8 km southwest of Cap-Pelé
399	D'Arcy Exploration Company Cape Bald No. 2	2	3.5 km south of the community of Cap-Pelé
400	D'Arcy Port Elgin No. 1	2	2.5 km north of the community of Port Elgin
401	Shell Oil Company–NBO Westmorland No. 1	2	12 km northeast of Memramcook East
402	Imperial–NBO Port Elgin No. 1	2	4 km north of Port Elgin
404	Maritime Oilfields Ltd. Memramcook West No. 2	3	At Little Dover
405	NBGO Scotts Hill No. 51	3	At Scotts Hill
406	NBGO Mud Creek No. 52	3	2 km north of Lower Coverdale
407	NBGO Lower Coverdale No. 92	3	1.3 km south of Lower Coverdale
420	Killarney Oil & Gas Development Company Ltd. T-1	3	3.5 km southwest of Lower Coverdale
421	Killarney Oil & Gas Development Company Ltd. T-2	3	3.5 km southwest of Lower Coverdale
422	Killarney Oil & Gas Development Company Ltd. T-3	3	3.5 km southwest of Lower Coverdale
423	Killarney Oil & Gas Development Company Ltd. T-4	3	3.5 km southwest of Lower Coverdale
424	W. Chappel 1 Moncton Hump Yard Water Well	3	In Moncton city limits, 3.5 km west of Marsh Junction
682	Noranda Lower Coverdale LC94-1	3	2 km north of Lower Coverdale
687	MariCo Steeves Mills No. 2	4	2 km south of Baltimore Station
688	MariCo Steeves Mills No. 4	4	1 km southeast of Baltimore Station
689	MariCo Downey No. 1	4	5 km southwest of Hillsborough (same well pad as Well 333)

UI No.	Company Well Name (in NBDNR Borehole Database)	Plate No.	Approximate Geographic Location
695	Shell Canada Limited Albert Mines No. 1	4	1.5 km northwest of Albert Mines
696	Shell Canada Limited Albert Mines No. 3	4	3 km north of Albert Mines
698	Shell Canada Limited Albert Mines No. 5	4	2.5 km southwest of Edgetts Landing
699	Shell Canada Limited Breau No. 1	4	2 km northwest of Upper Dorchester
702	MariCo Taylor Village OW No. 2	4	1.3 km northwest of Taylor Village
703	MariCo Albert Mines OW No. 4	4	At Edgetts Landing
704	Columbia Taylor Village No. 3	4	1.3 km southwest of Taylor Village
705	Columbia Beaver Brook No. 1	4	1.5 km north of Berryton
706	Columbia Beaumont L-24	4	1 km northeast of Beaumont
707	Columbia Boudreau A-36-2328	4	2 km northeast of Boudreau Village
708	Columbia Albert Mines L-44-2328	4	At Edgetts Landing
709	Columbia–Corridor Trans-Canada Highway G-100-2329	5	5.5 km east-southeast of Memramcook
711	Columbia–Corridor Coppermine Hill F-88-2329	5	2 km northeast of Woodhurst
713	Columbia No. J-67	–	NTS 21 I/11 outside report area-near Monteagle
716	Columbia–Corridor Coppermine Hill 2/F-88	5	2 km northeast of Woodhurst
749	Contact Exploration Inc. I-88	4	1 km northwest of Weldon
765	PetroWorth West S toney Creek E-08	4	1 km northwest of Dawson Settlement
790	PetroWorth West Stoney Creek A-08	4	1 km northeast of Dawson Settlement
DDH	Rio Tinto Canadian Exploration Ltd. No. P–11	–	NTS 21 H/12, outside report area
DDH	PNB Shepody No. 32	4	Shepody Marsh, just east of Hopewell Hill
DDH	PNB Shepody No. 33	4	Shepody Marsh, just east of Hopewell Hill
DDH	PNB Shepody No. 34	4	Shepody Marsh, just east of Hopewell Hill
DDH	Brunswick Mining and Smelting Corporation Ltd. CS-2	1	0.5 km east of Melrose